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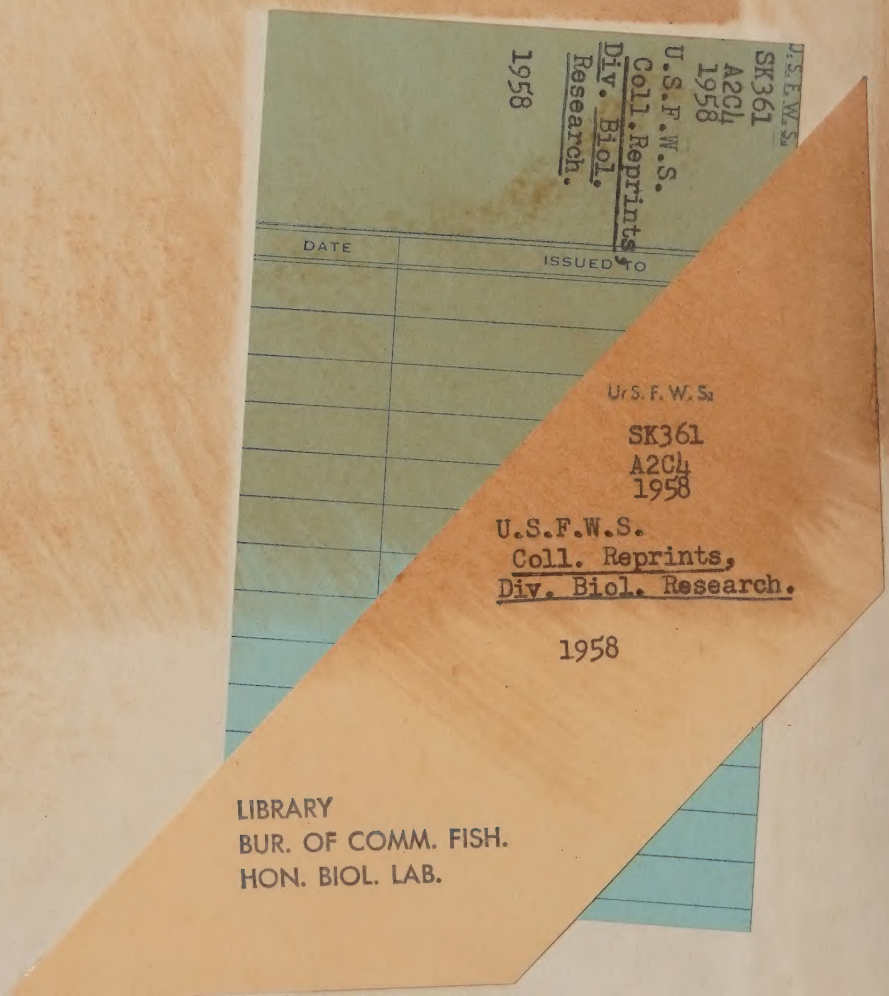
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A Pushnet for Quantitative Sampling of Shrimp in Shallow Estuaries

The shallow estuaries and bayous of the Gulf Coast are used extensively as nursery grounds by several species of commercially important shrimp. In our studies on the estuarine phase of the life cycles of *Penaeus setiferus* and *Penaeus aztecus*, sampling for post-larval and juvenile shrimp in the nursery areas presents a problem. The young shrimp tend to concentrate in areas of stiff salt-cord grass (*Spartina alterniflora*) where it is difficult to operate a beach seine efficiently.

Strawn (1954) describes a one-man pushnet used in shallow water grass flats by Florida bait shrimp fishermen and demonstrates its superiority over a seine for collecting in rooted vegetation. However, the Florida-type net apparently operates most efficiently in submergent vegetation such as turtle grass (*Thalassia testudinum*), which is less rigid than the salt-cord grass. Moreover, it was considered possible that repeated sampling with this net could excessively alter or disturb the stations of limited size occurring in our study area. Finally, we felt that a satisfactory index of abundance, based on a standardized unit of effort, could not be obtained using the Florida net.

Since it appeared that no existing gear was satisfactory for our sampling program, a new type pushnet was developed. This net was designed to yield quantitative samples while being operated by one man in stiff, rooted vegetation in depths of from 3 to 18 inches.

The pushnet described here consists of three units: the handle, the yoke and runners, and the net frame. Figure 1 shows the complete assembly with the major dimensions. The handle is made of 1½ inch aluminum tubing with a wooden crosspiece at the upper end. The yoke (Fig. 1) is a U-shaped pipe, with a short extension welded to the center to receive the handle. The angle of the yoke to the runner is fixed at 30° by a pipe welded in place between the back of the runner and the yoke (Fig. 2). The tubing used for construction of the yoke in this model consists of electrical conduit, though other material such as ¾ inch aluminum tubing would be stronger and lighter. At a point immediately in front of each arm of the yoke, a 4 x 4 inch T-plate, for attaching the net frame, is welded to the runner (Fig. 2). The runners are made of 12 or 16 gauge angle iron 1½ inches wide. The toes of the runners are four inches long and are bent upwards at approximately a 50° angle. A ½ inch galvanized pipe is welded across the bases of the runner toes, approximately one inch above the bottom, to act as a bumper for the net frame. The net frame is made of ¾ x ¾ inch white pine, and the net is attached by thin strips of wood tacked to the inside of the frame. The total weight of the pushnet is approximately 12 pounds and is thus easily operated by one person.

In assembling the pushnet, the male connection of the yoke is inserted into the handle and secured in place by two bolts (Fig. 1). The net frame is attached to the runners by two pairs of bolts through the free portion of the T-plates welded to the runners. All bolts are fitted with wing-nuts to facilitate dismantling or changing nets.

In actual use, the pushnet is pushed at a standard pace for a prescribed measured distance at each station. The weight and relatively narrow width of the pushnet tend to keep it on the bottom. The bumper bar, while protecting the net frame, also serves to dislodge many organisms from the vegetation. The net frame, fixed to and stabilized by the runners, fishes at a constant angle. The method of collecting is thus standardized, and it is our opinion that samples obtained in this manner are quantitative.

Samples collected over a period of five months, using No. 20 woven nylon mesh, contained considerable numbers of invertebrates and fishes. However, from our observations, repeated sampling at weekly intervals did not appreciably alter the stations.

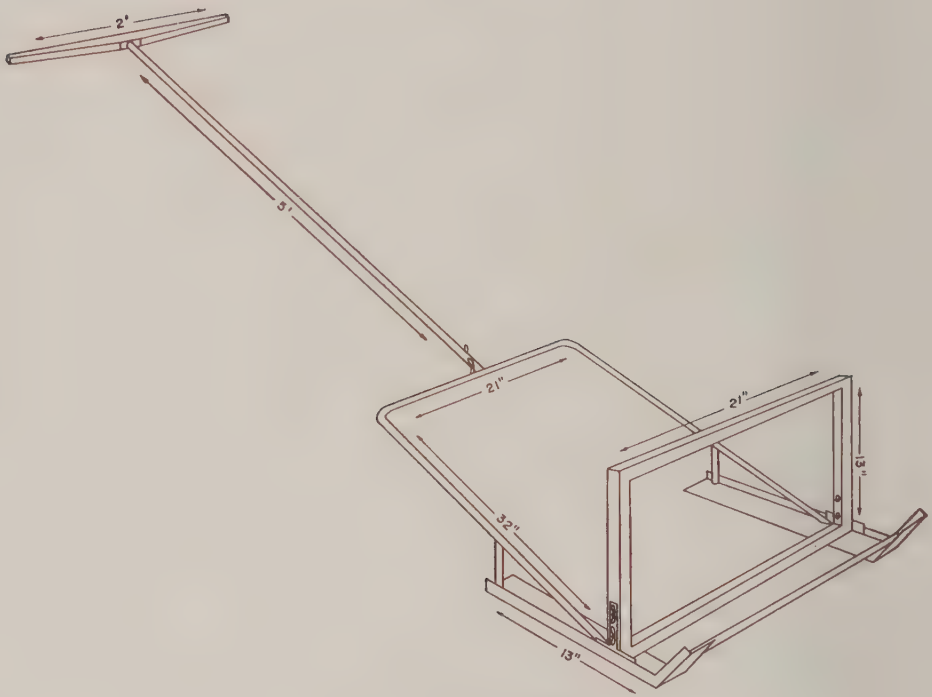

FIG. 1. Pushnet dimensions.

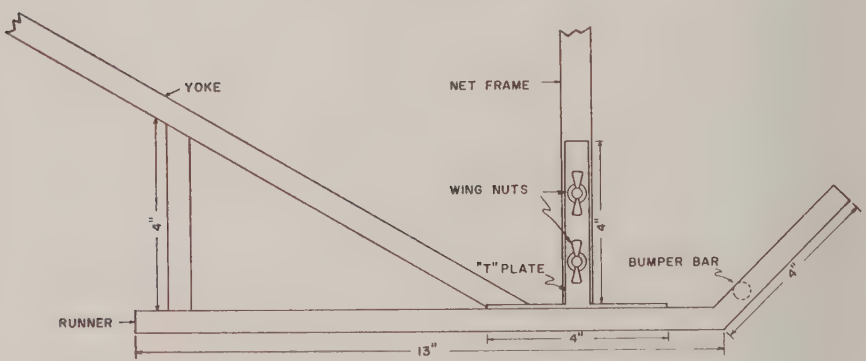

FIG. 2. Side view of pushnet showing construction detail.

We caught penaeid shrimp ranging in length from 6 to 85 mm in beds of partially inundated salt-cord grass as well as in shallow water devoid of vegetation. Shrimp larger than 85 mm probably did not commonly occur in these shallow water stations, since they were never seen leaping to avoid the net, as were the smaller shrimp.

It is considered possible, however, that the pushnet cannot capture the larger shrimp of the 6 to 85 mm size range in proportion to their actual abundance. Furthermore, *Penaeus setiferus* may be more adept than *Penaeus aztecus* in avoiding this net. De Sylva (1954) mentions this same possibility with reference to the Florida pushnet.

Attempts were made to determine the selectivity of the pushnet with reference to the size and species of shrimp. Both the pushnet and a 20-foot seine were operated within a shallow grassy area. The results, however, were inconclusive, since

the inefficient functioning of the seine made comparison of the catch between the two types of gear impossible.

REFERENCES

DeSylva, Donald P. 1954. The live bait shrimp fishery of the northeast coast of Florida. State of Florida, Board of Conservation, Technical Series No. **11**: 1–35.

Strawn, Kirk. 1954. The pushnet, a one-man net for collecting in attached vegetation. Copeia, **1954**(3): 195–197.

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BSERVATIONS UPON THE BIOLOGY, ECOLOGY AND LIFE HISTORY O THE COMMON SHRIMP, *PENAEUS SETIFERUS* (LINN.) ALONG THE SOUTH ATLANTIC AND GULF COASTS OF THE UNITED STATES

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OBSERVATIONS UPON THE BIOLOGY, ECOLOGY AND LIFE HISTORY OF THE COMMON SHRIMP, *PENAEUS SETIFERUS* (LINNAEUS), ALONG THE SOUTH ATLANTIC AND GULF COASTS OF THE UNITED STATES

by

W. W. Anderson*

In the United States, shrimp is by far the most luable fishery resource of the States bordering on e South Atlantic and Gulf of Mexico, being xceeded in volume only by the menhaden which, owever, it exceeds several times in value. This shery is in fact one of the top-ranking fisheries of e United States and Alaska both in value and olume.

Although numerous species of shrimp are found ong the South Atlantic and Gulf Coasts, only four re taken in quantities of commercial importance. he common shrimp, *P. setiferus*, is the most imortant commercial species, followed by the grooved rimps, *P. aztecus* and *P. duorarum*, and the seaob, *Xiphopeneus kroyeri*, which is of least imortance. All of these species belong to the family enaeidae. The common shrimp is of major imortance both on the South Atlantic and Gulf oasts; the major fisheries for the grooved shrimp re in the Gulf of Mexico (although to a lesser xtent on the South Atlantic also); and the seaob is utilized only in the Louisiana fishery, and here for drying purposes.

For a description of the development of the shery, methods of fishing, facilities, geographical istributions, main fishing areas, and seasons, pecies entering the catch and catch statistics, refer Anderson, Lindner and King, 1949.

The report to follow will touch upon the biology, cology and life history of the common shrimp, *enaeus setiferus*, along the South Atlantic and Gulf oasts of the U.S. The material presented was xtracted largely from Lindner and Anderson 956). To a lesser extent material was obtained om published papers listed under 'References.'

No attempt will be made to justify the statements ade as this has been done in the original papers.

Habitat

The common shrimp is most abundant in areas at are characterized by having an inland, brackish arsh connected by passes with an adjacent shallow, off-shore area of relatively high salinity and mud or clay bottoms. The off-shore characteristics seem to be required by adults and perhaps also by the larvae, while the inland marshes appear to be required by the post-larval pre-adults. The adults are rarely found in abundance in the Gulf of Mexico in depths greater than 30 fathoms, and along the South Atlantic Coast the distribution appears limited to a narrow coastal belt not more than 8 to 10 miles off the coast and in less than 10 fathoms of water. The pre-adults inhabit brackish water and at times are found in water that is almost fresh.

Spawning

The females do not carry the eggs after fertilization takes place but deposit them directly into the water. The male attaches a spermatophore to the female some time prior to the emission of the eggs. Eggs are fertilized upon emission by the sperm contained in the spermatophore. A female will produce from 500,000 to 1,000,000 eggs in a single spawning, and it is probable that there is more than one spawning a season—at least for some females.

Most, if not all, spawning takes place at sea and not in the estuarine inland waters. It appears likely from available evidence that there is little difference between the spawning seasons in any of the localities studied along the South Atlantic and Gulf Coasts between South Carolina and Texas. There probably is not more than about 2 weeks' difference in the beginning of spawning between any of the localities. Spawning may start later and end earlier in some sections than it does in others, but in all of the localities it probably begins either during the latter part of March or early in April and may possibly continue into November, although it is practically completed by the end of September. There is evidence of two peaks of spawning success—one in April and May and the other toward the end of the spawning period. These appear associated with and probably caused by the habits of the shrimp and temperature.

* Chief, South Atlantic Fishery Investigations, U.S. Fish & Wildlife Service.

Contribution No. 4
U. S. Fish & Wildlife Service
Bureau of Commercial Fisheries
Biological Laboratory
Brunswick, Georgia

Larval development

The larval development of the common shrimp apparently covers at least ten distinct stages excluding the demersal spherical egg. These consist of five naupliar, three protozoeal and two mysis stages.

In brief, the larval development of *P. setiferus* requires from two to three weeks. Some twenty to twenty-four hours after the egg is spawned, the nauplius breaks the chorionic membrane and emerges. This minute organism (about 0.3 mm. in length) is to a great extent at the mercy of the prevailing currents, but is capable of some movement. During the next twenty-four to thirty-six hours the nauplius undergoes five successive molts to become a protozoea of approximately 1.0 mm. in length. It now has seven pairs of appendages, a pair of sessile compound eyes and a complete alimentary tract consisting of mouth, esophagus, stomach, intestine, and anus. Prior to this stage the food of the nauplius has been the yolk material carried over from the egg. This food supply is now exhausted, and henceforth the protozoea must capture its own food in order to survive. This transitional period is a critical one.

The third protozoea stage is followed by the first mysis which is about 3.5 mm. in length and possesses fourteen pairs of functional appendages and on the abdomen five pairs of buds which will soon become the pleopods. In the second mysis the pleopods are well developed, and rudimentary gills have made their appearance on the thoracic somites. With the succeeding molt the organism ends its larval phase and assumes the general proportions of a miniature adult. At the end of two post-larval stages and fifteen to twenty days after hatching, the young shrimp is only 5 to 6 mm. in length and is still planktonic. During this period of early development, the young shrimp have moved from the saline offshore spawning area to the brackish inside marshes, bays, and estuaries. Upon reaching these 'nursery grounds' they adopt for the first time, it is believed, a benthic existence.

The factors responsible for this inshore movement of larval shrimp have not been determined, but it is believed that for the young to reach the nursery grounds they must encounter favourable incoming currents. While capable of some movement, and perhaps responsive to a salinity gradient, they would certainly be quite helpless against outgoing currents. If spawning occurred at sea close to an inlet, the eggs could be swept through the passes on incoming currents, and the larvae reach the nursery grounds within a few hours.

Young shrimp

Young shrimp approximately 7 mm. in length are found during the spring and summer months in the brackish areas which serve as their nursery gr for the next four to eight weeks of their exist This habitat is a rich feeding ground with sha water, muddy bottoms, rather widely fluctua seasonal temperatures, and moderate to low sali

As the young grow, they move from the sha waters of the marsh, bayou and lagoon into deeper creeks, rivers and bays, making their appearance on the inside fishing grounds when a 50 mm. long. The young first appear in estuarine fishing grounds in June or July, depen upon the area, and by July or August they begun to make their appearance in outside wa Generally in the estuarine waters there is a grad in size of the shrimp, smaller shrimp occurrin those waters farther inland and larger shrimp those waters nearest the open ocean. This grad in size appears more closely associated with loc than with salinity.

Growth

Growth data were obtained from shrimp mar in various areas of the fishery along the So Atlantic and Gulf Coasts of the U.S. The effec range of these data is from 100 mm. to 180 r From other sources the growth of shrimp sma than 100 mm. has been estimated.

Growth is rapid during spring, summer and e fall, and negligible during winter. This sugg that the periods of rapid and slow growth are a ciated with temperature, and if this is so, we co expect them to vary somewhat from year to year with locality. Our understanding of the growt further complicated by the fact that shrimp different sizes grow at different rates. The ra growing season is from about March until the en October.

We believe that shrimp reach about 80 mm. length (from tip of rostrum to the end of tels approximately two months after hatching. On basis and applying the established growth rates example of growth is: Spawning on May 1; yo shrimp reached a length of approximately 80 m by July 1, 110 mm. by August 1, 130 mm. by S tember 1, 145 mm. by October 1, and 158 mm. November 1. Growth from November 1 to Ma 1 would be negligible but if we assume that 2 m growth occurred during this period our shrimp wo be about 160 mm. in length on March 1— beginning of the spring rapid growing season. shrimp would then reach a length of approxima 168 mm. by April 1 and about 173 mm. by Ma It would be approximately 1 year old, mature spawning during this spring season. Since spawning season covers a period of 6 months longer any number of combinations of growth possible depending on the month spawned.

grations

Migrations were determined by tagging. The mon shrimp has very definite patterns of move- nts but these vary in different areas.

We found that in one respect the movements of rked shrimp were similar in all localities studied the South Atlantic and Gulf Coasts of the U.S. er the young shrimp first appeared on the inland ing grounds they gradually worked their way vards the sea. This movement from inside waters outside waters speeds up during two periods of year—at the onset of winter and in the spring. ese two periods seem to be associated with two ups of shrimp, the early-spawned group, and the r-spawned group.

Once the shrimp reach the outside waters their vements vary with size of shrimp, locality, and parently also the time of the year. Small shrimp, cm. or less in total length, did not undertake any ensive movements. Upon reaching the outside ters they remained there, almost immediately acent to their inland nursery grounds. The ge shrimp, more than 13 cm. in total length, owed quite distinct behaviour patterns which ied with locality. These will be summarized on geographical basis.

Atlantic Coast : Briefly our results indicate that st of the common shrimp of the Atlantic Coast, r migrating from inshore to offshore waters, do move into very deep water far from the coast. tead, they make seasonal migrations parallel to shoreline, moving southward during the fall and y winter and northward in late winter and early ing. During late spring and summer, their vements are limited and random, so that they ain in the same general area. The larger speci- ns are much more prone to move considerable ances than are the smaller individuals. The gest known southward migration was performed a shrimp released in North Carolina in October recaptured 95 days later off the east coast of rida—about 360 miles south of where it was ased. The greatest northward migration was rded for a specimen released in central Florida January and recaptured 168 days later off the t of South Carolina after it had gone about 260 s.

Northern Gulf East of the Mississippi River : Tag- was limited to fall and winter months in the between Mobile Bay, Alabama and the mouth of Mississippi River. All that can be indicated at ent about the movement of the shrimp in this n is that during the fall and winter they tend to e into deeper water and toward the mouth of the issippi River.

Northern Gulf West of the Mississippi River : In brief, along the Louisiana coast west of the Mississippi River the large shrimp moved offshore and scattered out during fall and winter. At all times they appear to be drifting about, like cattle on open range land. The only definite patterns were offshore and onshore movements, which evidently were associated with temperature changes and spawning, and a tendency to concentrate in certain areas, probably because of better feeding conditions. We believe the more or less aimless wanderings of the shrimp (but not the offshore and onshore movements) represent a search for food.

There appeared to be a natural barrier at the Mississippi River for we found neither east-west nor west-east crossings.

Central Texas : Results of tagging in this area are inconclusive due to distribution of the fishery when the marking was done. Indications are that shrimp from the central and southern part of Texas move south to the coast of Mexico during the fall and early winter, probably comparable to the movement along the South Atlantic Coast of the U.S. Likewise there is evidence of a springtime south-to-north migration from northern Mexican waters to Texas waters.

Longevity

Mortality of shrimp is apparently high and the number that live more than one year is small with respect to the total population and is probably not of great practical importance. Some shrimp live at least 16 months and possibly longer.

Temperature and salinity relations

While our temperature and salinity data are considered inadequate and are not as extensive as the biological observations, certain correlations are indicated in sections of the fishery where our most complete records are available. These observations may eventually be shown to apply to the entire fishery.

It appears that growth slows to practically nothing near the end of October when the water temperature drops to about 20°C and is resumed in the spring when the temperature again reaches approximately that value.

Spawning appears to be more closely associated with rising and falling temperatures than with absolute temperature. The comparatively abrupt rise in the spring temperatures coincides rather closely with the beginning of the spawning season and may, indeed, initiate it, while the season seems to terminate as soon as the temperatures begin to decline rapidly in the fall, even though they are at

that time appreciably higher than those which evidently induced spawning in the spring.

At first appraisal it would appear that there is little relationship between temperature and migrations. For example, in Louisiana, spring-spawned shrimp appear first in the trawl catches in inside waters in June, in outside waters adjacent to the coast in July, and offshore in August. This well-defined outward movement cannot be temperature-induced, since it occurs well before there is an appreciable drop in temperature. Judging from the behaviour of the shrimp during this period, we believe the offshore movement is primarily associated with the approach of adulthood and spawning. However, this offshore movement is later accelerated by falling temperatures. The phenomenon, evidently initiated by physiological changes in the organism itself, seems to be hastened and intensified during fall and winter by the external factor of declining temperatures.

Concomitant with the accelerated fall and winter offshore movement of the adults and sub-adults, the smaller, more immature shrimp move from the very shallow inland waters toward the Gulf of Mexico. These very small shrimp, which during summer are most abundant towards the heads of the bays are, during mid-winter, more abundant near the mouths of the bays and in the Gulf adjacent to the shore, where the temperatures are not so readily depressed.

A similar situation exists along the South Atlantic Coast. However, when the temperature begins to decline rapidly in the fall, the larger shrimp move southward along the coast rather than offshore as they do in Louisiana.

This change in habitat caused by winter temperatures can probably best be described as a general shift towards warmer waters, but with all sizes of shrimp still maintaining their size-locality separations.

Sudden, severe drops in temperatures in some localities will kill shrimp and in other localities will cause them to move offshore considerably beyond their normal range. It appears from the winter distributions of shrimp that the smaller shrimp are probably less susceptible to cold than are the larger ones.

The reaction of the shrimp to salinity is not clear-cut. The young go to the inland areas of low salinity, and on approaching adulthood they move towards the more saline waters of the sea. It seems to us that the shrimp (at least the sub-adults) are rather insensitive to large fluctuations in salinity, but that they are quite sensitive to small changes in temperature.

In every locality, our trawl samples would almost always yield the smallest shrimp in the inside waters farthest from the sea, and the largest in the ou waters. In general there was a progression i size of trawl-caught shrimp, with the smallest in the waters of lowest salinity and the large the highest salinity. However, due to other plicating factors this apparent relation betwee of shrimp and absolute salinity within rela large ranges of salinity probably does not exist. relation normally is between size and locality. is, certain sizes of shrimp will be found in c localities at certain seasons regardless of wha salinity may be (within relatively wide limits) a particular locality and time. This does not however, that there is no relation between size salinity. Why is it that as the shrimp increa size they head for the sea ? We suspect this to reaction to salinity, related to spawning or mat We have observed that if the salinity become low in an area, the shrimp will leave.

In winter there is a definite relation between and temperature, with the largest shrimp seekin warmest temperatures. This correlation does exist during summer. In fact summer size- perature relation is negative, but we can see no c and-effective connection.

General

Perhaps the shrimp is its own worst en Data from Louisiana (the area of greatest a dance) are suggestive of this. In spite of app continuous spawning throughout the entire se evidently only the earliest and latest spawning really successful, and the latest spawning is conc tant with the earliest-spawned shrimp moving shore from the inland nursery grounds. The se successful spawning in Louisiana (and the last i other localities) does not seem to occur until numbers of shrimp have departed from the nu grounds. Also in Louisiana, waves of oncor young appear to be spaced about 2 months a which suggests spawning successes coinciding mass departures of the preceding wave from inner to the outer nursery areas.

Preliminary analysis of some of our data inclu that derived from tagging, suggests that the between loss from natural mortality and gai weight through the rapid growth of the indivi animals is such that the total poundage of sh available to the fisherman would be increased i shrimp were protected from the time they appea the inside fishing grounds in summer until they m to outside waters in fall. Likewise, on this s basis, it might be advantageous to afford prote to the small shrimp while they are growing ra during early spring, or possibly to this same g during winter.

It is rather widely accepted that in certain areas f its range (notably Louisiana) the shrimp is robably the most important animal both with res-ect to species-mass and food conservation. When e consider this point it is unfortunate that we do ot know enough about shrimp to be able to predict ith any assurance what will happen to the popu-tion when man does this or that. For example hile we have suggested that it may be advisable to mit fishing of small shrimp, on the other hand, eavy exploitation of inside waters may result in a ore extended spawning success owing to a reduced nnibalistic predation, with the obvious conse-uence of greater production.

We therefore arrive at the conclusion that well-ntrolled fishing experiments, together with addi-onal research, are required before we can determine ith any degree of accuracy how the shrimp popu-tion will respond to changes in fishing effort or in shing seasons. Because the growth of the shrimp so rapid, the experiments, if followed by com-etent observers and with adequate catch figures, eed not be drastic in their approach. On the basis f our present information, experimental fishing of nall shrimp during the periods when they are rowing rapidly seems most promising.

REFERENCES

ANDERSON, W.W., J. E. KING, and M. J. LINDNER (1949).—Early stages in the life history of the common marine shrimp, *Penaeus setiferus* (Linnaeus). *Biol. Bull.*, 96(2) : 168-172.

ANDERSON, W. W., M. J. LINDNER, and J. E. KING (1949).—The shrimp fishery of the southern United States. *U.S. Fish and Wildlife Service*, Sep. 121, 2(2).

KING, JOSEPH E. (1948).—A study of the reproductive organs of the common marine shrimp, *Penaeus setiferus* (Linnaeus). *Biol. Bull.*, 94(3) : 244-262.

LINDNER, M. J., and W. W. ANDERSON (1956).—Growth, migration, spawning, and size distribution of shrimp, *Penaeus setiferus*. *Fish. Bull.* : *U. S. Fish and Wildlife Service*, 56(106) : 555-645.

PEARSON, J. C. (1939).—The early life histories of some American Penaeidae, chiefly the commercial shrimp, *Penaeus setiferus* (Linnaeus). *Bull. U.S. Bur. Fish.*, 49(30) : 1-73.

WEYMOUTH, F. W., M. J. LINDNER, and W. W. ANDERSON (1933).—Preliminary report on the life history of the common shrimp, *Penaeus setiferus* (Linnaeus). *Bull. U.S. Dept. Comm. Bur. Fish.*, No. 14.

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Use of Mononitrophenols Containing Halogens as Selective Sea Lamprey Larvicides

The invasion of the upper Great Lakes by the sea lamprey and its destructive attacks upon important fishes have engendered a considerable effort to control the numbers of this predator. Means for combating this pest may be applied effectively and economically during those parts of its life-cycle that are spent in streams (*1*). Destruction or diversion of the adults during their spawning runs (the terminal stage of the life-cycle) is a practicable procedure. This is being accomplished by electrical barriers which kill, or repel, the adults before they reach the spawning grounds (*2*). A serious shortcoming of this control technique is the time lag which occurs before the effect of such measures can become apparent. At least six generations of larval lampreys, already resident in stream beds, continue to grow, transform into adults, and migrate into the lakes to begin their existence as parasites. Thus it may be as much as seven years before the lamprey population of a lake basin shows any marked decrease after the blocking of all streams suitable for spawning.

The life-cycle of the sea lamprey may also be broken effectively at the larval stage by the regulated application of selectively toxic chemicals. This treatment of streams inhabited by sea lampreys should produce more immediate control of the species than is being achieved by present techniques. In the course of screening various chemicals in a search for selective sea lamprey larvicides (*3*), we discovered six mononitrophenols containing halogens which are significantly more toxic to sea lamprey larvae than to other aquatic organisms (*4*). We also found that the conversion of four of these substances to their respective sodium salts increases their general utility without significantly affecting their useful biological activity (Table 1).

Laboratory experiments were conducted in 10-lit glass battery jars, each containing 5 lit of water. These vessels were aerated by means of standard stone air-breakers and were maintained at a constant temperature by immersion in specially constructed troughs. Test animals in each experiment were larvae of the sea lamprey (*Petromyzon marinus*) and fingerlings of at least two of the following species of game fishes (choice of the species of game fishes depended on availability): rainbow trout (*Salmo gairdneri*), brown trout (*Salmo trutta*), and bluegill sunfish (*Lepomis macrochirus*). To each test container we added two specimens of the species chosen to be exposed to a chemical. Appropriate amounts of the compound were then added to the test jars to produce a desired concentration. Generally, 24 simultaneous replications were run with the same species at each such concentration. All laboratory tests were conducted for a 24-hour period at a water temperature of 55 ± 1°F.

Table 1. Differential toxic effects among larval lampreys and fishes exposed to mononitrophenols containing halogens. Sodium salt is expressed in parts per million of free phenol.

Name and form of compound	Concentration required to kill all lamprey larvae (ppm)	Concentration required for significant mortality† among test animals (ppm)		
		Rainbow trout	Brown trout	Bluegill
2-Bromo-4-nitrophenol				
Free phenol	5	13	11	
Na salt	7	15		
3-Bromo-4-nitrophenol				
Free phenol	5	11		15
5-Chloro-2-nitrophenol				
Free phenol	3	5	5	
2,5-Dichloro-4-nitrophenol				
Free phenol	3	13	7	
Na salt	5	17		
3,4,6-Trichloro-2-nitrophenol				
Free phenol	5	17	15	
Na salt	13	23		
3-Trifluormethyl-4-nitrophenol*				
Free phenol	2	9	7	
Na salt	2	7		

* α,α,α-trifluoro-4-nitro-*m*-cresol. † Mortality of approximately 10 percent of all test animals

The specific toxic effects displayed by the compounds studied under these controlled conditions are summarized in Table 1.

Our principal objective has been to locate chemicals which are acutely toxic to larval sea lampreys at low concentrations and which, at the same concentrations, are not toxic to other fishes inhabiting the same stream environments. A further requirement was that these selectively toxic materials should be capable of destroying the larvae in a relatively short period of time. We believe that the differential toxicities displayed by these mononitrophenols (with the exception of that exhibited by 5-chloro-2-nitrophenol) cover a sufficiently broad range of concentrations to permit their regulated application in natural streams to destroy lamprey larvae without concurrent damage to other fish. Requirements for a short treatment period are likewise met by these compounds. At minimum effective concentrations of each of the chemicals, all of the larvae were killed in less than 16 hours. At higher concentrations the time was much less. Several of the compounds killed all of the lampreys in less than 45 minutes without apparent harm to the game fish which remained exposed to these concentrations for 24 hours.

We have also tested 3,4,6-trichloro-2-nitrophenol and 3-trifluormethyl-4-nitrophenol in a running water raceway in which natural stream conditions were simulated. In these cases aqueous solutions of the sodium salts of each of these phenols were applied under conditions where continuous flow required their regulated metering into the "stream" during the entire test treatment period.

The raceway utilized for this purpose was a rectangular concrete trough, 65 ft long, 6 ft wide, and 30 in. deep. Water for the "race" was pumped from Lake Huron; its flow into the experimental "stream" was regulated by a "V" weir. For each test treatment undertaken, an artificial stream bed was constructed on the floor of the raceway with materials taken from the beds of local rivers. Typical stream features such as pools and riffles were reproduced. Test animals were released in the raceway sufficiently in advance of a treatment to allow them to become adjusted to the "stream." Each experimental treatment (at a particular concentration) was conducted for a 24-hour period. The larvicidal com-

pound was metered into the water by an electric, motor-driven, dual-piston, fluid-proportioning device. This machine pumped from a concentrated stock solution of the chemical and delivered the concentrate, slightly diluted with flush water, to a perforated pipe laid on the stream bed at the head of the test stream [illegible].

Under conditions that simulated treatment of an actual stream, the toxic effects of each of the substances upon fishes seemed to be considerably less than the effects which were observed under laboratory-jar test conditions. On the other hand, concentrations of the materials lethal to all larval lampreys were essentially the same in the jar tests and in treatments of the simulated stream.

For example, in raceway tests of 3,4,6-trichloro-2-nitrophenol (applied as an aqueous solution of its sodium salt), all lamprey larvae were killed by concentrations as low as 12 parts per million. Sustained exposure to a concentration of 40 parts per million of the compound (the highest concentration that we applied experimentally) did not cause any significant toxic symptoms to appear among either rainbow trout or brown trout. Furthermore, exposure to this concentration did not cause any evident harm to any of the following additional test species: brook trout (*Salvelinus fontinalis*), rock bass (*Ambloplites rupestris*), bluegill sunfish, pumpkinseed sunfish (*Lepomis gibbosus*), lake chubs (*Couesius plumbeus*), northern creek chubs (*Semotilus atromaculatus*), logperch (*Percina caprodes*), crayfish (*Cambarus* spp.), dragonfly larvae (Anisoptera), and caddisfly larvae (Trichoptera). Several other species of fishes used in the raceway tests displayed some susceptibility to the higher concentrations of the chemical which we introduced. Yellow perch (*Perca flavescens*) and white suckers (*Catostomus commersoni*) were not affected by a concentration of 32 parts per million, but significant mortalities among these two species occurred during the application of a concentration of 40 parts per million. A considerable number of mortalities occurred among bullheads (*Ictulurus melas* and *I. nebulosus*) during all applications of concentrations of 20 parts per million or more of the phenol.

A comparable accentuation of the selectively toxic properties of 3-trifluormethyl-4-nitrophenol was observed when treatments with this chemical were conducted in our raceway. The results we obtained in our raceway tests with both compounds suggest that all of the mono nitrophenols we have studied may b more useful for treatment of actua streams than could have been anticipate from our laboratory-jar tests (*5*).

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References and Notes

1. V. C. Applegate and J. W. Moffett, "The se lamprey," *Sci. American* 192, No. 4, 36 (1955
2. L. F. Erkkila, B. R. Smith, A. L. McLai "Sea lamprey control on the Great Lakes 1953 and 1954," *U.S. Fish Wildlife Serv. Spe Sci. Rept. Fisheries Ser. No. 175* (1956).
3. V.C. Applegate *et al.*, "Toxicity of 4,346 chem icals to larval lampreys and fishes," *U.S. Fi Wildlife Serv. Spec. Sci. Rept. Fisheries Se No. 207* (1957).
4. We are indebted to the following organizatio for preparing and supplying chemical sampl and for technical advice in the development these materials for our specific use: The Do Chemical Company; Progressive Color an Chemical Company; Diamond Alkali Com pany; Niagara Chemical Division, Food Ma chinery and Chemical Corporation; Monsan Chemical Company; Michigan Chemical Com pany; chemistry department, Bucknell Unive sity; and chemistry department, University Michigan.
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Offshore Spawning of the Striped Mullet, *Mugil Cephalus,* in the Gulf of Mexico

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OFFSHORE SPAWNING OF THE STRIPED MULLET, *MUGIL CEPHALUS*, IN THE GULF OF MEXICO.—The biology of the common or striped mullet, *Mugil cephalus* Linnaeus, has been the subject of numerous investigations, yet the locations of spawning grounds remain controversial. According to Higgins (1927, Rept. U. S. Comm. Fish., Bur. Fish. Doc. 1029: 624–627), Hildebrand and Schroeder (1927, Bull. U. S. Bur. Fish., 43(1): 192–196), Breder (1940, COPEIA (2): 138–139), Gunter (1945, Publ. Inst. Mar. Sci. Texas, 1(1): 51–52), and Taylor, *et al* (1951, Survey Mar. Fish. No. Carolina: 115) mullet spawn either inshore or within a few miles of the coast. Broadhead (1953, Fla. State Bd. Conserv., Tech. Ser. (7): 21) stated that indirect evidence, based on reports of commercial fishermen, indicates that spawning occurs in the Gulf, probably 5 to 20 miles offshore. Dekhnik (1953, Daklady Akademia Nauk, USSR; 93(1): 201–204) concluded that spawning of Black Sea mullet takes place chiefly near the coast, although some eggs of the species were found in plankton tows made far offshore.

For the past three years one of the projects of the Gulf Fishery Investigations has been a continuing study of the biology of East Lagoon, a narrow body of water slightly more than one mile long, in the northeastern end of Galveston Island, Texas. Waters of the lagoon are governed chiefly by tidal exchange via its opening into Bolivar Roads approximately three miles from the Gulf. Included in the information obtained during this study are pertinent observations on striped mullet. Large concentrations of roe mullet were observed frequently around the mouth of the lagoon from late October to mid-November. Although numerous schools of post-larval *M. cephalus*, 25–30 mm. in total length, appeared regularly by mid-December, and often were taken in the nets, periodic plankton collections made in the area never have yielded fertilized eggs or early larvae. This suggests that spawning takes place beyond the range of tides and currents moving in and out of Bolivar Roads. In partial support of this suggestion, the dense schools of roe mullet disappeared suddenly from the vicinity of the lagoon and Galveston beaches for about 10 days in late November, 1956. Upon reappearing in scattered small schools, the fish were found to be spent. This occurrence agrees closely with the repeated observations of Florida commercial fishermen reported by Broadhead (*op. cit.*).

The presence of fertilized eggs and/or early larvae coupled with observations of suspected spawning activities should be undeniable proof that spawning has occurred. These conditions were met during a recent tuna long-lining cruise (December 3–13, 1956) of the U. S. Fish and Wildlife Service M/V OREGON in the north central Gulf of Mexico. The general area occupied was over the continental slope in depths from 500 to 900 fathoms, and 40–50 miles southeast of the Mississippi River Delta.

Shortly after midnight on December 11, the OREGON was drifting in 755 fathoms of water at approximately 28°20′ N. Lat., 88°45′ W. Long. While engaged in dip-netting over the side of the slowly drifting ship, we were surprised to see a compact school of approximately 200 striped mullet appear beneath our night-light. The fish were large adults and some were thought to be females because of their distended abdomens. Dip-net captures later proved this to be correct. We could not determine whether or

not more than one school was involved, but mullet varying in number from about 50–250 circled the vessel every few minutes until just before dawn, swimming either at or within a few feet of the surface. As the sea was calm, we had a clear view of their activities.

From time to time as the schools came into sight, one or more groups of 3–6 fish would leave the school and swim around close to the surface in an erratic manner. Their subsequent behavior resembled that described by Breder (*op. cit.*); apparently spawning was taking place. As our field of visibility was limited to the illuminated area provided by the floodlight (about 30 feet out from and 50 feet along the side of the OREGON), a single group was seldom under observation for more than a minute. The actions described, therefore, are a composite of the behavior patterns of the 25 to 30 groups witnessed throughout the period of observation. In a typical group, the males, noticeably smaller and more slender, maintained positions slightly behind what was ostensibly a female. Five or six times while they remained in view, one or more of the males would quickly move up beside or below the female, nudging and pressing against her abdomen with head and body. Often during this action the individuals thus engaged would quiver and cease swimming momentarily, sometimes rising to the surface. The unoccupied males swam rapidly back and forth in the immediate vicinity until they in turn behaved in a similar fashion. We did not observe any of the "tight" formations of spawning groups described by Breder (*op. cit.*). There was little of the splashing and "milling around" that characterized the spawning activities of the closely related species, the silver mullet, as described by Anderson (1957, U. S. Fish and Wildlife Service, Fish. Bull. 119(57): 397–414). There was no evidence of milt or eggs in the water, but this could have been due to the drifting of the ship and the relatively small numbers of active spawners.

Seven fish were dip-netted from three of the spawning groups and identified as *Mugil cephalus*. Three were females with fork lengths of 285 mm., 290 mm., and 258 mm. The males measured 258 mm., 257 mm. (2), and 240 mm. Eggs could be extruded from the females with the slightest abdominal pressure and milt ran freely from the males.

In an attempt at fertilization, we placed milt and eggs from a captured male and female in an 8-quart plastic bucket containing sea water. The experiment was not successful. However, we later learned that Anderson (*op. cit.*) also failed in fertilization attempts with silver mullet using an aquarium of several gallons capacity, but succeeded when he used small culture jars. The reason(s) for this difference in results is unknown.

A series of eight sub-surface plankton tows with a #1 monel mesh net was made during long-line operations. The net, with a 15-inch diameter opening, was towed at an average speed of 4 knots. On numerous occasions throughout this period we observed thousands of little silvery fish in the area, swimming near the surface in small, closely packed schools. The plankton samples, sorted at the Galveston laboratory, yielded over 2,000 of these, or strikingly similar fish, varying in total length from 4 mm. to 25 mm. The larger specimens (20 mm. and over) were identified as striped mullet by careful comparison with known post-larvae of the species previously taken in local collections. A developmental series down to 9 mm. in length, tentatively identified as *M. cephalus,* was obtained by working backwards through successively smaller sizes. For possible confirmation, 30 specimens of varying sizes were picked indiscriminately out of more than 2,000 in the plankton collection and forwarded to W. W. Anderson at the Brunswick laboratory. He identified 20 of these specimens as *Mugil* species, not *Mugil curema.* In qualifying his identification Anderson pointed out that the fantail mullet, *Mugil trichodon* Poey, also present in the Gulf, has the same anal fin-ray count as *M. cephalus.* As the very young of the fantail mullet never have been described, larval forms of the two species could have been confused. However, as fantail mullet occur in the northern Gulf only as occasional strays, and as spawning activities observed in the early morning hours of December 11 were unquestionably those of striped mullet, such a possibility is extremely remote.

Additional evidence that we had witnessed actual spawning of *M. cephalus* was the presence of several hundred fertilized eggs of the species in the plankton collection. The eggs, in early stages of development, were identified by comparing them, microscopically, with those stripped from the captured females.

While by no means excluding the possibility of inshore spawning, the foregoing observations and plankton collection results, including size range of the larvae and post larvae, should establish conclusively that spawning of striped mullet does occur offshore in relatively deep water and for a period of at least several weeks.

Other offshore observations of *Mugil cephalus* are of possible significance and are offered for consideration. No fish were captured, but the

observations were made by fisherman who had fished commercially for mullet for many years, and all were positive in their identification.

On November 27, 1950, the OREGON was at anchor off the Texas coast 30 miles southeast of the Aransas Pass jetties in 30 fathoms of water. Personnel aboard the vessel observed large striped mullet in schools of about 50–200 at various times from 0340 to 1252 hours. That afternoon, while the vessel was underway, similar schools were sighted on four occasions between 1336 and 1430 hours, from 27°30′ N, 96°29′ W to 27°23′ N, 96°23′ W. Depths ranged from 42 to 59 fathoms. Unfortunately, actions of the mullet were not noted.

William T. Cothrun, a commercial fisherman of Sabine Pass, Texas, reported, in a personal interview, that he had encountered immense shoals of striped mullet in late November, 1950, some 65 miles south of Mobile, Alabama, in 20–25 fathoms of water. Mr. Cothrun was aboard the P-83, an oil company motor vessel. According to his account, the ship steamed through the shoals for several hours. The mullet were swimming slowly in an easterly direction, frequently with their heads out of water, at which times "smacking" noises were audible.

The authors are indebted and grateful to Mr. Anderson for his kind assistance in the preparation of this paper.—EDGAR L. ARNOLD, JR. *U. S. Fish and Wildlife Service, Galveston, Texas,* AND JOHN R. THOMPSON, *U. S. Fish and Wildlife Service, Pascagoula, Mississippi.*

Seasonal Variations in the Oceanographic and the Marine Biological Features in the Waters of French Oceania (Marquesas)

The Pacific Oceanic Fishery Investigations (POFI) of the U. S. Fish and Wildlife Service is investigating the tuna resources of French Oceania, with particular emphasis in the waters near the Marquesas Islands. Two surveys have been conducted by POFI vessels, one during the Southern Hemisphere winter (August–October 1956) and one during the Southern Hemisphere summer (January–March 1957). During both surveys, the general oceanic circulation features, the productivity of the ocean waters, and the abundance of the tuna and their availability to longline and live-bait fishing methods were investigated.

Preliminary study of the oceanographic data reveals that the flow of water incident to the Marquesas–Tuamotu islands was from the southeast. In the general region of the islands, and down-current from the islands, there was evidence of large-scale, but weak, eddies. The westerly transport through a section near 145° W. longitude, between the surface and 500 meters, was $5.8 \times 10^7 m^3$ during the summer cruise, $4.5 \times 10^7 m^3$ during the winter cruise.

Although the summer-winter variations in the general circulation features were not striking, the seasonal variations in the concentration of inorganic phosphate and the indices of productivity at the lower trophic levels were very evident. During the Marquesan summer, the supply of inorganic phosphate in the surface waters, the rate of photosynthesis as measured by the uptake of C^{14}, and the zooplankton volumes were, in general, one-half the values observed during the Southern Hemisphere winter.

The surface tunas were apparently more abundant during the Marquesan summer. On two summer cruises, 104 tuna schools and associated bird flocks were observed in January and 97 schools in February, as compared with 42 schools sighted on a similar traverse in September during the Marquesan winter. The surface tuna bit at a slow rate, however. During the Marquesan summer, 99 schools were fished; 36 responded with a catch of one or more tuna and 12 with a catch of 100 or more from each school. During the winter, only one school of tuna was successfully fished. Ten were chummed. Using longlines, the catch rate of the deep-swimming tunas was 6.0 per 100 hooks during the summer, and 0.3 during the winter.

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Variations with Depth of Oceanographic Properties Along the Equator in the Pacific

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Abstract—The vertical distribution along the equator in the Pacific of temperature, salinity, density, oxygen, and phosphate, from the sea surface to 1000 meters, and the anomaly of the dynamic height of the sea surface and other isobaric surfaces above the 700-decibar surface are shown. In each of the figures, the available data have been partitioned according to the date of the observation into two periods, July to December and January to June, which are designated in the text as summer and winter, respectively. The figures include data from stations within one degree of latitude north or south of the equator between 110°W and 135°E longitude.

The surface of the sea, relative to the 700-db surface, slopes upward, east to west, approximately 0.8 dynamic meters; the value for the slope is 5.0×10^{-8} during both summer and winter. The longitudinal pressure gradient does not extend much below the layer of relatively large vertical density gradient. At the depth of $\sigma_t = 26.5$, 250–300 m, relatively little east-west slope is evident.

In the surface layer (sea surface to top of the thermocline), temperatures along the equator are lower in the eastern Pacific during both periods; the thermocline is comparatively level west of the 180th meridian, sloping upward to the east of this longitude. Temperatures are appreciably lower and concentrations of inorganic phosphate are higher in the surface layer in the eastern Pacific during the summer, both reflecting the temporal and longitudinal variations in divergence and upwelling.

The oxygen minimum, centered at a depth of approximately 450 m, is a continuous feature from 100°W longitude (eastern limit of the profiles) to near 170°E longitude, with the lowest concentrations in the east (≤ 0.5 ml/L) increasing to 1.5 to 2.0 at the westward limit. West of 170°E longitude, concentrations at 450 m rapidly increase to 3.0 ml/L.

In recent years, numerous profiles illustrating the vertical distribution of properties along meridional (north-south) sections crossing the equator in the Pacific have appeared in the literature. Data thus presented included, for examples, those from cruises of the *Carnegie* [*Sverdrup* and others, 1942], the *Hugh M. Smith* [*Austin*, 1954a; *Montgomery*, 1954; and *King* and others, 1957], the *Albatross* [*Jerlov*, 1956], and various Japanese research vessels [*Mao* and *Yoshida*, 1955]. These data, which were rather widely spaced with respect to both geography and time, were inadequate for consideration of seasonal variations in trans-Pacific vertical profiles, particularly along the equator.

During August through October 1956, 12 vessels participated in EQUAPAC, a quasi-synoptic oceanographic survey of the equatorial Pacific between approximately 20°N and 10°S latitude and 135°W to 135°E longitude. Data from EQUAPAC, plus those from previous and subsequent surveys, now make it possible to study in some detail the vertical distribution and seasonal variations of properties along the equator. In the accompanying figures, profiles for temperature, salinity, density (σ_t), oxygen, and inorganic phosphate, and the anomaly of the dynamic height of the sea surface and other isobaric surfaces above the 700-db surface are shown.

The stations selected for use in the figures were all located within one degree of latitude (60 nautical miles) north or south of the equator. Pertinent information for the stations, each of which has been designated by a letter-number combination on the figures, is listed in Table 1. Wherever available, interpolated data from each station were plotted at standard depths, otherwise observed data were used. In drawing the contours, an effort was made to suppress configurations which apparently resulted from station-to-station temporal variations. This was not always possible without violating plotted values and consequently localized irregularities appear in the isopleths. Some available data were not utilized because they appear to have been recorded during seasons or years which were atypical for their longitude. For example, at *Carnegie* Station 98 near 175°W, the temperatures from the surface to depths somewhat below the thermocline were considerably higher (+6° to +10°C at 200 m) than those for nearby stations, resulting in a pronounced trough in the isotherms.

TABLE 1 – *Pertinent data for oceanographic stations included in Figures 1–6*

Station[a]	Date	Latitude	Longitude	Reference
		° ′	° ′	
July to December				
Ka 613	Aug. 1, 1956	00 38 N	130 20 E	*Kagoshima University* [1957]
Ke 621	Aug. 2, 1956	01 00 N	135 08 E	*Kagoshima University* [1957]
Sa 32	Aug. 18, 1956	00 29 N	139 49 E	*Suda* [1957]
Sa 14	Aug. 5, 1956	00 30 N	151 02 E	*Suda* [1957]
Ho 31	Aug. 24, 1956	01 00 S	156 46 E	*Scripps Inst. Oceanogr.* [1957]
Ho 10	Aug. 13, 1956	00 02 S	163 57 E	*Scripps Inst. Oceanogr.* [1957]
Or 10	Oct. 4, 1956	00 12 S	170 03 E	Unpublished data; Institut Français d'Océánie
Or 12	Oct. 13, 1956	00 15 N	176 28 E	Unpublished data; Institut Français d'Océánie
Dai 21	July 13, 1956	00 10 N	179 57 W	*Shizuoka Pref. Fish. Exp. Sta.* [1957]
St 34	Sep. 15, 1956	00 01 N	174 59 W	*Scripps Inst. Oceanogr.* [1957]
Sm 23	July 10, 1950	01 00 S	171 57 W	*Cromwell* [1954]
St 21	Aug. 29–30, 1956	00 02 N	166 59 W	*Scripps Inst. Oceanogr.* [1957]
Sm 164	Sep. 27, 1956	00 01 S	159 52 W	*Austin* [1957]
Al 111	Nov. 15, 1947	00 02 N	152 07 W	*Bruneau* and others [1953]
Sm 32	Sep. 27, 1951	01 00 S	149 58 W	*Austin* [1954a]
Sm 113	Sep. 2, 1956	00 02 N	143 03 W	*Austin* [1957]
Sm 144	Nov. 20, 1955	00 16 N	140 11 W	*King* and others [1957]
Sm 62	Aug. 19, 1956	00 04 S	134 54 W	*Austin* [1957]
Sm 94	Nov. 7, 1955	00 11 S	119 58 W	*King* and others [1957]
Ba 23	Oct. 12, 1955	00 58 N	116 03 W	*Scripps Inst. Oceanogr.* [1956]
Sm 73	Oct. 31, 1955	00 12 S	112 25 W	*King* and others [1957]
Da 3558	Sep. 18, 1928	00 18 S	99 07 W	*Thomsen* [1937]
Ba 58	Nov. 28, 1955	00 00	91 41 W	*Scripps Inst. Oceanogr.* [1956]
Ba 51	Nov. 15, 1955	00 00	83 47 W	*Scripps Inst. Oceanogr.* [1956]
January to June				
Ja 97	June 14, 1938	00 49 N	149 54 E	Unpublished data, U.S.N. Hydrogr. Of.
Ja 101	June 17, 1938	00 48 N	153 49 E	Unpublished data, U.S.N. Hydrogr. Of.
Al 143	Jan. 3, 1948	00 09 S	163 23 E	*Bruneau* and others [1953]
Sm 25	Feb. 18, 1952	00 02 N	179 59 E	*Stroup* [1954]
Ca 98	Apr. 30, 1929	00 18 N	173 59 W	*Fleming* and others [1945]
Sm 40	Mar. 4, 1952	00 01 N	169 00 W	*Stroup* [1954]
Sm 35	Feb. 20, 1950	00 04 S	158 22 W	*Cromwell* [1951]
Sm 9	Jan. 31, 1952	00 06 S	155 14 W	*Stroup* [1954]
Sm 88	Mar. 20, 1957	00 01 N	145 02 W	*Wilson* and *Rinkel* [1957]
Sm 22	June 5, 1952	00 43 S	140 11 W	*Austin* [1954b]
Sm 43	Feb. 25, 1957	00 00	130 00 W	*Wilson* and *Rinkel* [1957]
Sm 3	Jan. 23, 1957	00 03 N	123 17 W	*Wilson* and *Rinkel* [1957]
Sm 6	Jan. 24, 1957	00 22 N	120 11 W	*Wilson* and *Rinkel* [1957]
Sm 12	Jan. 26, 1957	00 06 N	113 54 W	*Wilson* and *Rinkel* [1957]
Sm 15	Jan. 27, 1957	00 12 S	110 12 W	*Wilson* and *Rinkel* [1957]

[a] Al, *Albatross*; Ba, *Spencer F. Baird*; Ca, *Carnegie*; Da, *Dana*; Dai, *Daifuji Maru*; Ho, *Horizon*; Ja, Jap. 90029; Ka, *Kagoshima Maru*; Ke, *Keilen Maru*; Or, *Orsom III*; Sa, *Satsuma*; Sm, *Hugh M. Smith*; and St, *Stranger*.

There are two profiles for each of the fields depicted, one for the period July to December, the other for January to June. These two periods, for simplicity of terminology and discussion in the subsequent text, have been designated as 'summer' and 'winter,' respectively, without implication as to the summer and winter seasons recognized in higher latitudes. The division of the year into the two six-month periods resulted primarily from consideration of the seasonal variability in the trade winds and also from the necessity of selecting periods within which there would be a sufficient number of stations to provide adequate data for the sections. The southeast trades (of particular significance along the equator) are at maximum constancy and force in August–September, minimum in March–April.

Vertical profiles along the equator are of diversified interest. As expressed by *Montgomery* and *Palmén* [1940], the equator is the ideal location for determining the longitudinal pressure gradient. At the equator there can be no cross-stream gradient because deflecting force and compensating pressure gradient both vanish. Of interest to both the physical oceanographer and the marine biologist are the east-west (and seasonal) variations in the

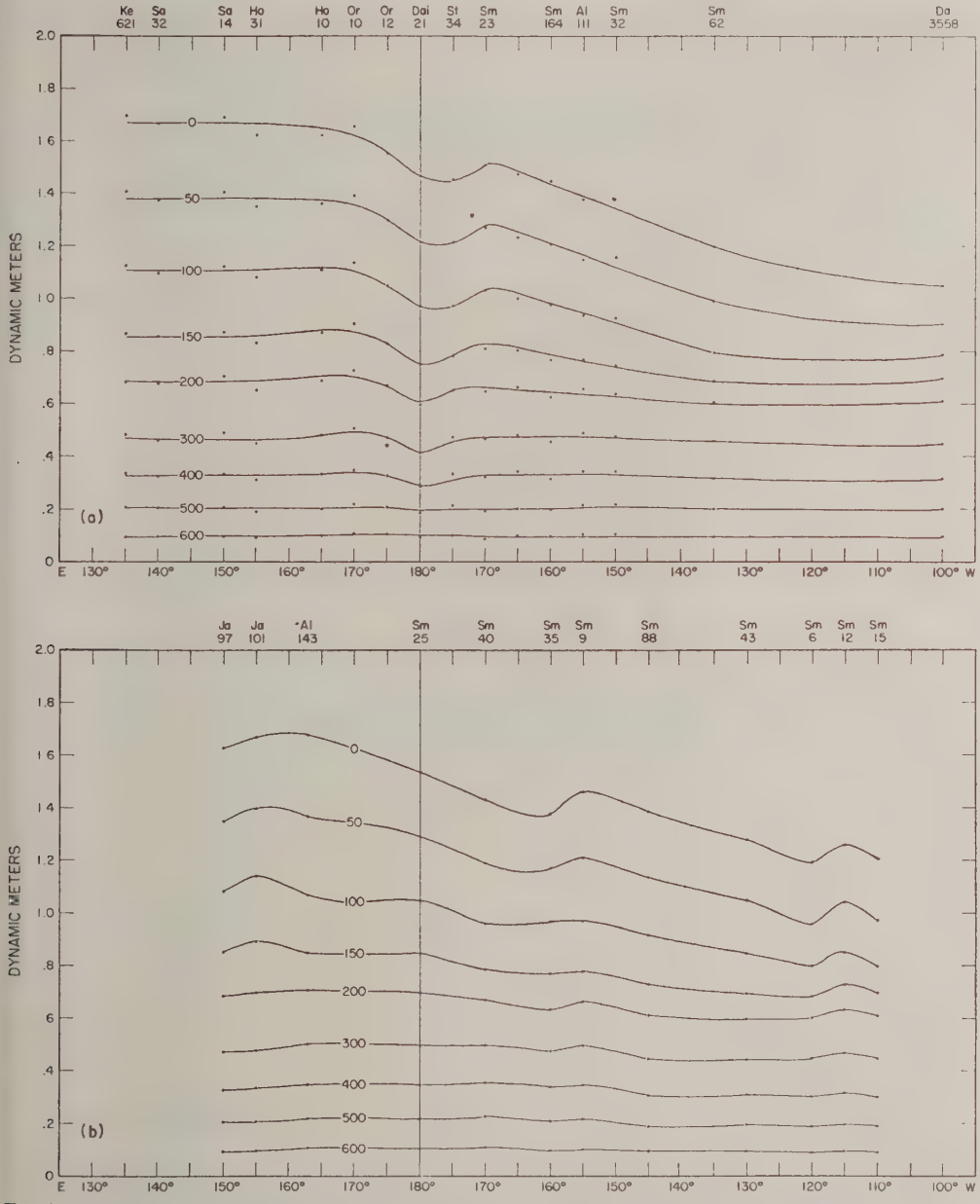

FIG. 1 – Anomaly of the dynamic height of the sea surface and other isobaric surfaces above the 700-db level; (a) July to December; (b) January to June; see Table 1 for position, date, and source of data for each station designated along the top borders

slope of the thermocline and of the equatorial divergence and upwelling.

In Figure 1 we have shown the anomaly of the dynamic heights for the sea surface and other isobaric surfaces, all relative to the 700-db assumed level of no motion. During both periods, the sea surface slopes upward, east to west, with a mean value for the slope of 5.0×10^{-8} (0.8 m in 15×10^3 km) during both the summer and the winter. *Montgomery* and *Palmén* [1940] calculated the slope to be 4.5×10^{-8}.

Between the two periods there are variations in

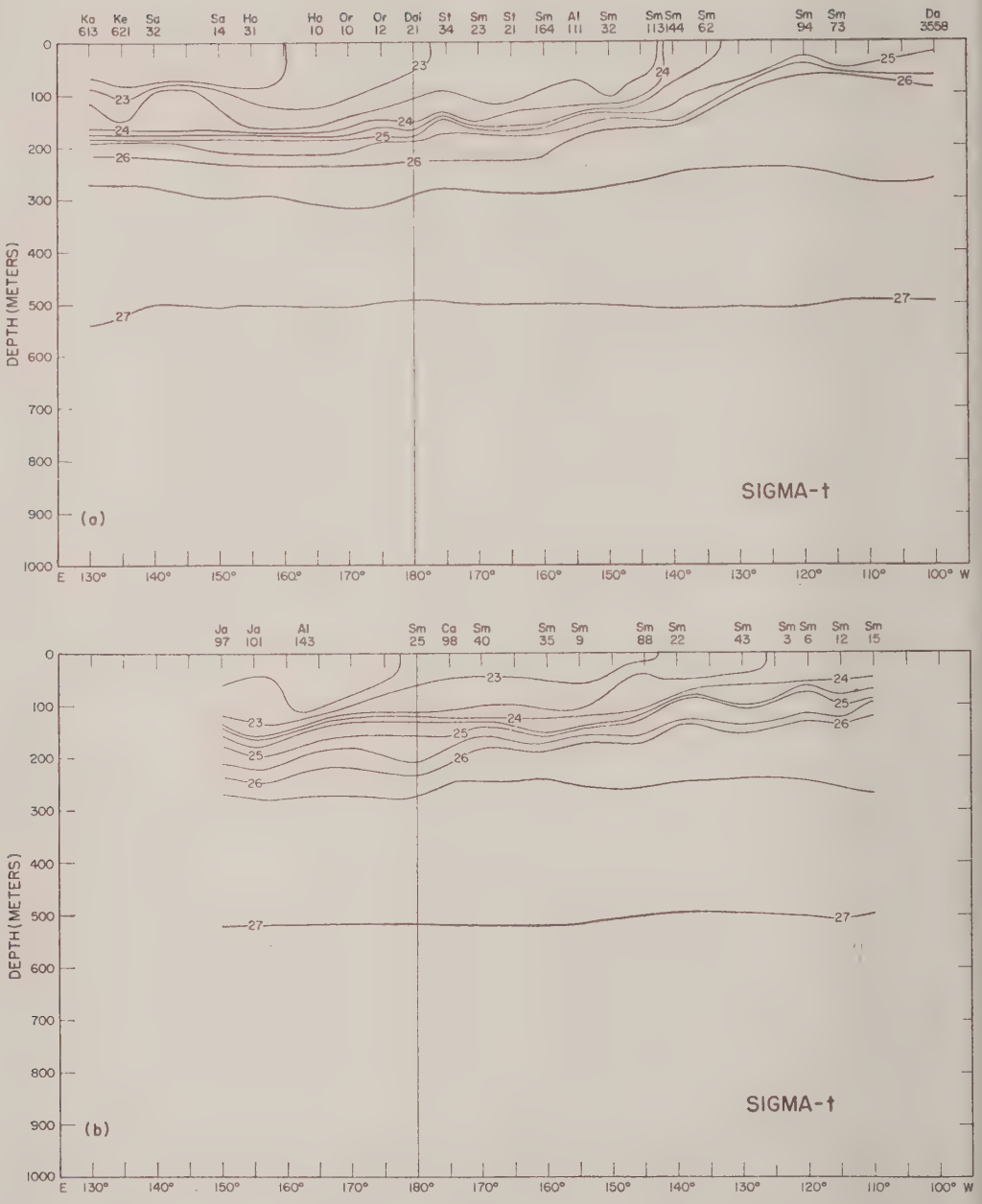

FIG. 2 – Density; contour interval 0.5 units of sigma-*t*; (a) July to December; (b) January to June

the height of the sea surface in the eastern Pacific. During the summer, east of approximately 165°W longitude, the surface is 10–15 dynamic centimeters lower (relative to the 700-db surface) than during the winter. The dips in the anomaly of the dynamic height of the sea surface near 180° in the summer and 165°W in the winter are difficult to explain. Enough stations are involved in each case to suggest that they are a real feature.

Montgomery and *Palmén* [1940, Fig. 43] demonstrate that the longitudinal pressure gradients in the Atlantic and the Pacific do not extend below the layer of relatively large vertical gradient in density (hereinafter referred to as the stable layer).

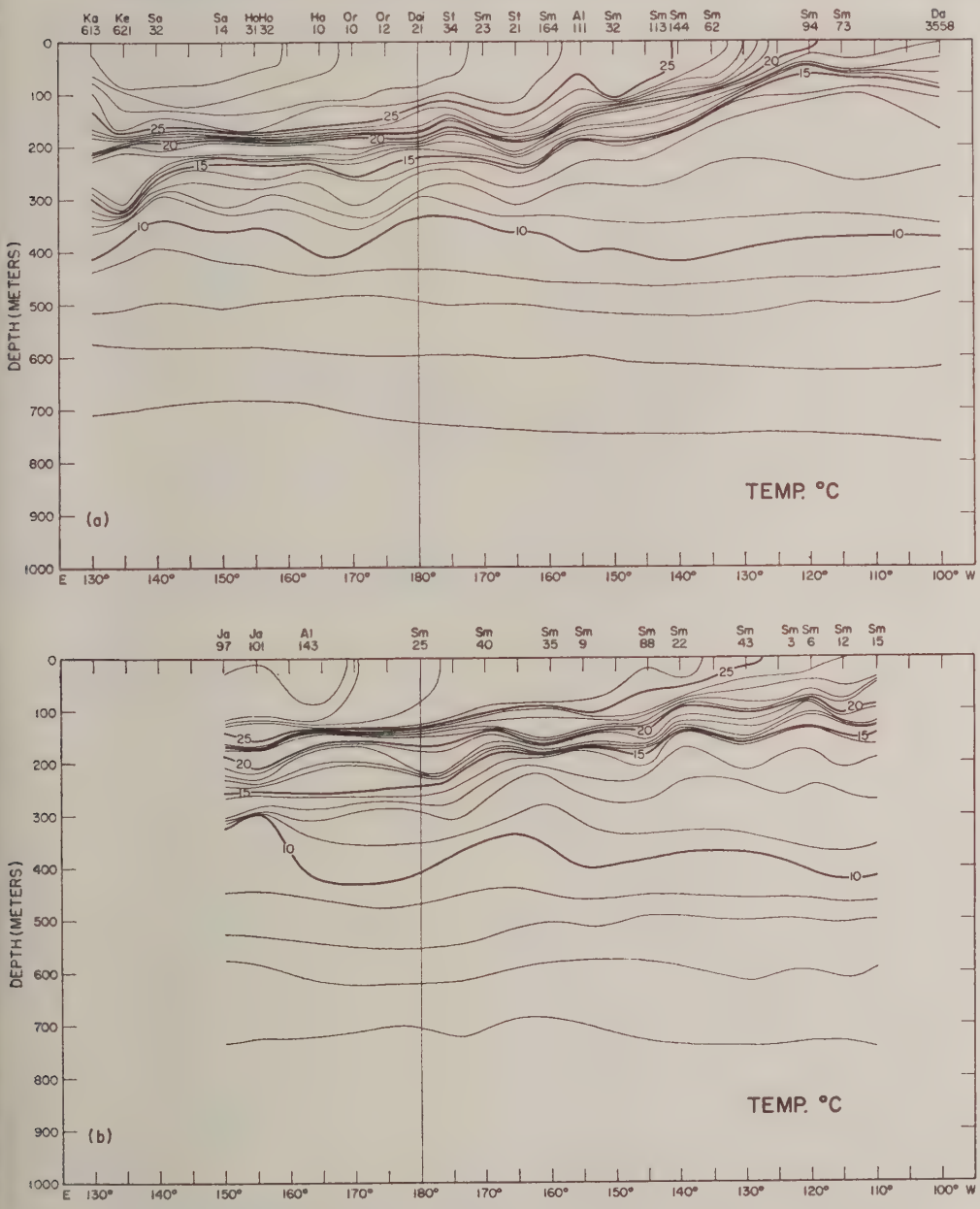

FIG. 3 – Temperature; contour interval 1°C; (a) July to December; (b) January to June

For their analyses of the situation in the Pacific, data for only two positions were available, one at 99°07′W, the other at 134°44′E longitude. Using the data from the stations included in Figure 1, the σ_t distribution along the equator is shown in Figure 2. Although, when comparing Figures 2a and 2b, variations in density are evident in the surface layer (surface of the sea to top of the stable layer) and in the east-west slope of the stable layer, the 26.5 isopleth (250–300 m) in both figures shows relatively little east-west slope.

During the summer, the east-west slope of the stable layer is steeper than in the winter east of 160°W; conversely to the west of 160°W, the slope

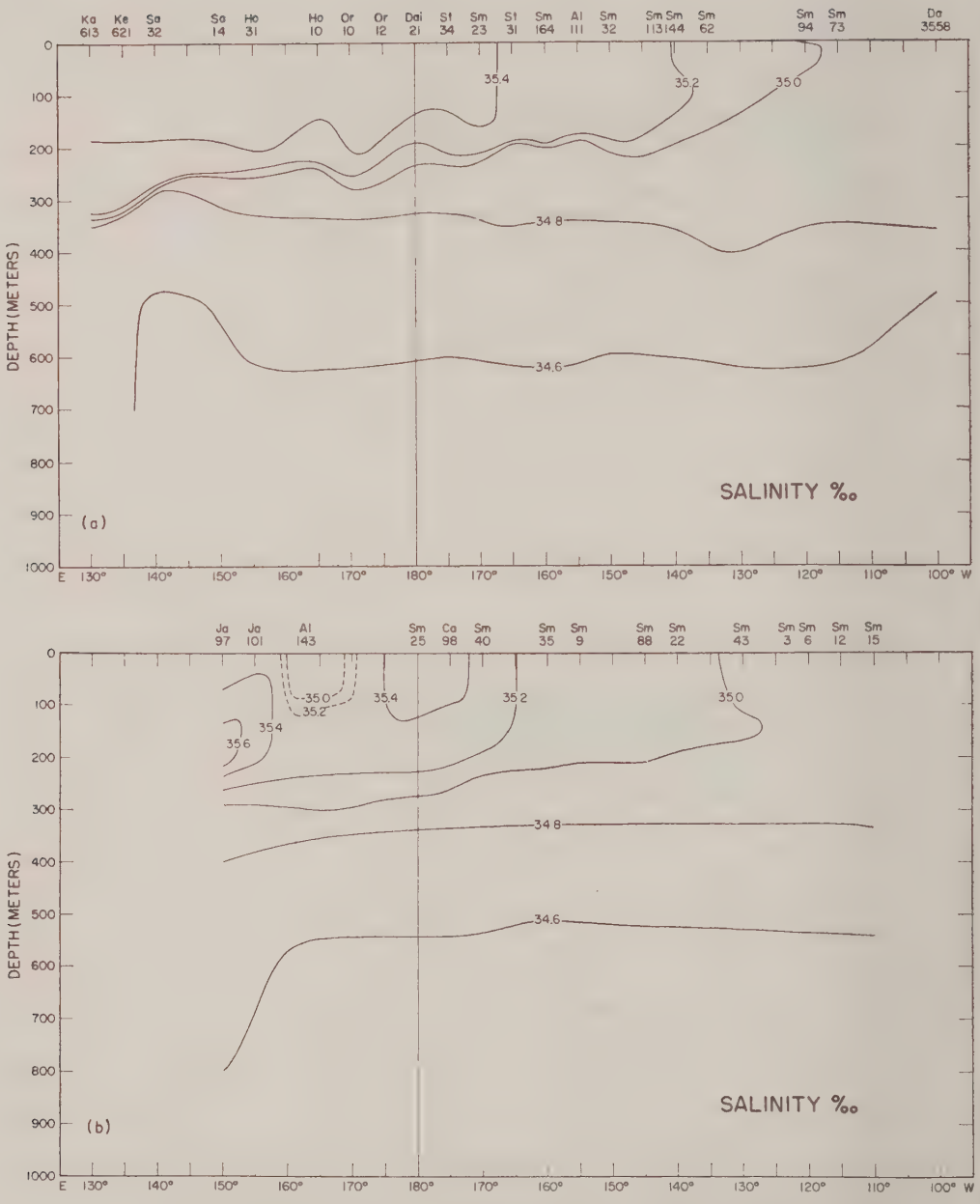

FIG. 4 – Salinity; contour interval 0.2 per mille; (a) July to December; (b) January to June

is less in summer than in winter. In terms of depth of the stable layer, in the west it is deeper and in the east shallower in summer than in winter. These variations, evident in Figure 2 (and 3), reflect the greater volume of lighter, warmer water in the western Pacific during the July to December period.

Variations in density and thus in the results of the geostrophic calculations in the tropical Pacific are principally a function of variations in temperature. The vertical distribution of temperature is shown in Figure 3. In general, the temperatures in the surface layer are cooler in the eastern Pacific than in the west; the thermocline is comparatively

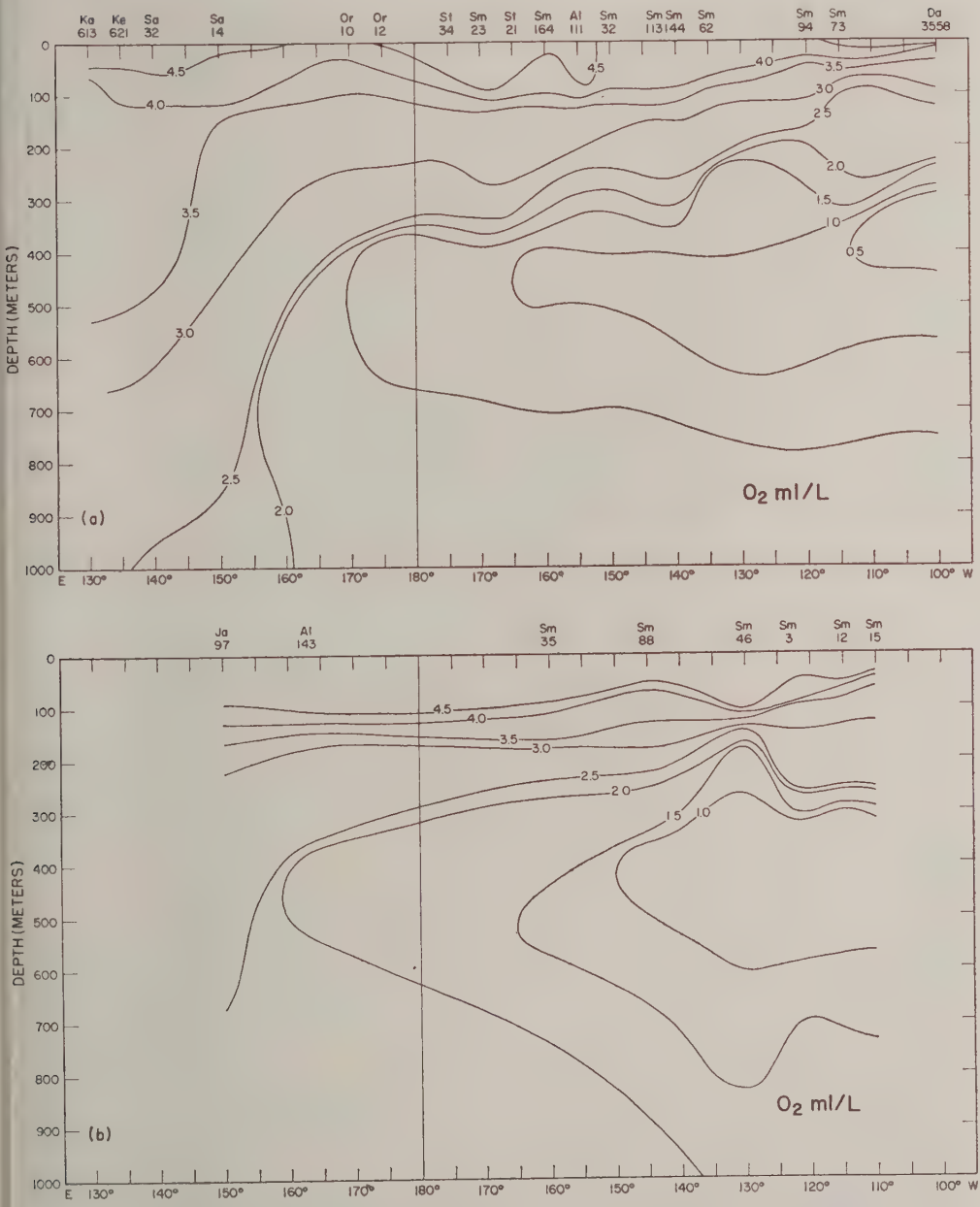

FIG. 5 – Oxygen; contour interval 0.5 milliliters per liter; (a) July to December; (b) January to June

level in the western Pacific, sloping upward east of the 180th meridian [*Sverdrup* and others, 1942, Fig. 197]. During the summer period, particularly in the eastern Pacific, the temperatures of the surface layer are considerably cooler than during the winter, while in the west, summer temperatures are warmer to greater depths.

Austin and *Rinkel* [1957], in part through a comparison of meridional temperature sections, have shown that there is an east-west variation in upwelling at or near the equator in the Pacific with the maximum mixing of the deeper, cooler waters with those at the surface being in the eastern central Pacific. In addition, they state

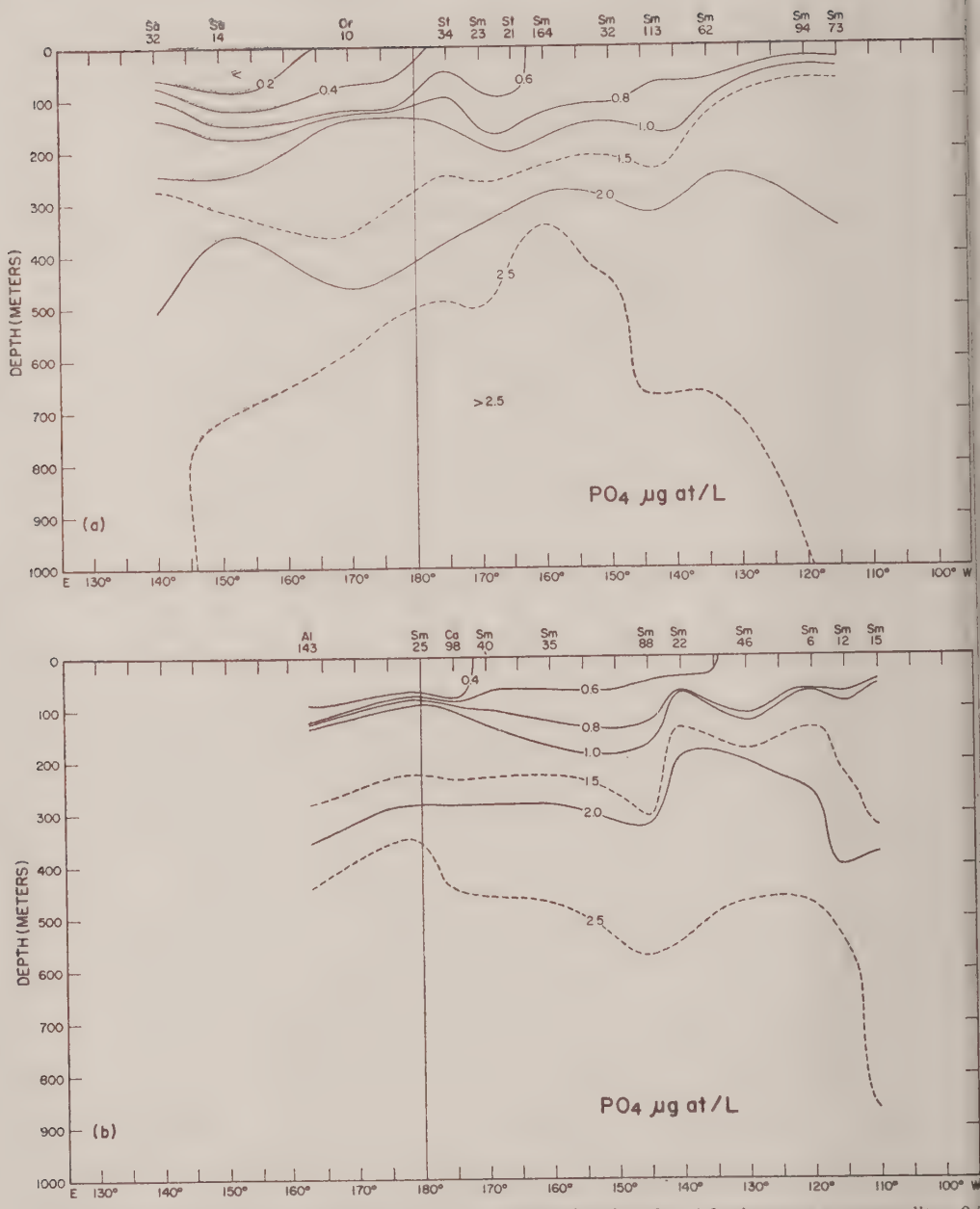

FIG. 6 – Inorganic phosphate; contour interval 0.2 for concentrations less than 1.0 microgram atoms per liter; 0.5 for concentrations greater than 1.0 microgram atoms per liter; (a) July to December; (b) January to June

that the period of most active upwelling is during August through October, the period of the maximum constancy and force of the easterly component of the southeast trade winds. These conclusions are reflected in the cooler surface waters in the eastern portion of Figure 3a.

The more active upwelling in the eastern Pacific during the summer is also reflected in the vertical distribution of salinity (Fig. 4). In the eastern Pacific, the mixing processes associated with upwelling limit the penetration of the waters of the intermediate salinity maximum into the northern hemisphere [*Austin*, 1954b; *Austin* and *Rinkel*, 1957]. In the western Pacific, these waters pene

trate to 5° to 10°N [*Mao* and *Yoshida*, 1955]. In the eastern Pacific the effect of the mixing by upwelling of the higher salinity water of the maximum with the waters in the surface layer is more pronounced in the summer than in the winter (Fig. 4).

The most pronounced feature in the vertical distribution of oxygen, both summer and winter (Fig. 5), is the oxygen minimum centered at about 450 m beneath the sea surface. The lowest oxygen concentrations in the minimum are in the eastern Pacific (0.5 ml/L or less), increasing progressively westward to about 165°E where the minimum essentially terminates.

The waters at depths of the oxygen minimum (temperature about 9.0°C, salinity 34.70 $^{0}/_{00}$) are characterized by *Sverdrup* and others [1942, Fig. 196] as Equatorial Water which is probably formed off the coast of South America by gradual transformation of the Subantarctic Water and which spreads to the north and to the west. The oxygen minimum is shallower than the salinity minimum (1000 m, T = 5.5°C, S = 34.50–34.58 $^{0}/_{00}$) which Sverdrup denotes as the 'core' of the Antarctic Intermediate Water.

The concentrations of inorganic phosphate in the surface waters (Fig. 6) are comparatively higher in the eastern Pacific, 0.6–0.8 μg at/L as compared with ≤ 0.2 μg at/L in the western half of the ocean. In general, east of 160°W they are higher during July to December, the period of most intensive upwelling.

References

Austin, T. S., Mid-Pacific oceanography, pt 3, transequatorial waters, August–October 1951, *U. S. Fish Wildlife Serv. Spec. Sci. Rep. Fisher. 131*, 17 pp., 13 fig., 1954a.

Austin, T. S., Mid-Pacific oceanography, pt 5, transequatorial waters, May–June 1952, August 1952, *U. S. Fish Wildlife Serv. Spec. Sci. Rep. Fisher. 136*, 86 pp., 1954b.

Austin, T. S., Summary, oceanographic and fishery data, Marquesas Islands area, August–September, 1956 (EQUAPAC), *U. S. Fish Wildlife Serv. Spec. Sci. Rep. Fisher. 217*, 186 pp., 1957.

Austin, T. S., and M. O. Rinkel, *Variations in upwelling in the equatorial Pacific*, presented at the 9th Pacific Science Congress, Bangkok, Thailand, 1957.

Bruneau, L., N. G. Jerlov, and F. F. Koczy, Physical and chemical methods, *Rep. Swedish Deep-Sea Expedition*, **3**, *Physics and Chemistry 4*, pp. 100–112, 1953.

Cromwell, T., Mid-Pacific oceanography, January–March 1950, *U. S. Fish Wildlife Serv. Spec. Sci. Rep. Fisher. 54*, 76 pp., 1951.

Cromwell, T., Mid-Pacific oceanography, pt 2, transequatorial waters, June–August 1950, January–March 1951, *U. S. Fish Wildlife Serv. Spec. Sci. Rep. Fisher. 131*, 13 pp., 32 fig., 1954.

Fleming, J. A., C. C. Ennis, H. U. Sverdrup, S. L. Seaton, and W. C. Hendrix, Observations and results in physical oceanography, Oceanography 1B (Scientific results of Cruise VII of the *Carnegie* during 1928–1929), *Carnegie Inst. Wash. Pub. 545*, 315 pp., 1945.

Jerlov, N. G., The equatorial currents in the Pacific Ocean, *Rep. Swedish Deep-Sea Expedition*, **3**, *Physics and Chemistry 6*, pp. 129–154, 1956.

Kagoshima University, Faculty of Fisheries, *Oceanographical observation made during the international cooperative expedition EQUAPAC in July–August, 1956 by M. S. Kagoshima Maru and by M. S. Keiten Maru*, 68 pp., 1957 (processed).

King, J. E., T. S. Austin, and M. S. Doty, Preliminary report on expedition EASTROPIC, *U. S. Fish Wildlife Serv. Spec. Sci. Rep. Fisher. 201*, 155 pp., 1957.

Mao, Han-Lee, and K. Yoshida, Physical oceanography in the Marshall Islands area, *Geol. Surv. Prof. Pap. 260-R*, pp. 643–684, 1955.

Montgomery, R. B., Analysis of a *Hugh M. Smith* oceanographic section from Honolulu southward across the Equator, *J. Mar. Res.*, **13**, pp. 67–75, 1954.

Montgomery, R. B., and E. Palmén, Contribution to the question of the equatorial counter current, *J. Mar. Res.*, **3**, 112–133, 1940.

Scripps Institution of Oceanography, *Data report; data collected by Scripps Institution vessels on EASTROPIC expedition, September–December 1955*, sponsored by Office of Naval Research, SIO Ref. 56-28, 1956 (processed).

Scripps Institution of Oceanography, *Data report; data collected by Scripps Institution vessels on EQUAPAC expedition, August 1956*, sponsored by Office of Naval Research, SIO Ref. 57-25, 1957 (processed).

Shizuoka Prefectural Fisheries Experimental Station, *EQUAPAC oceanographic and meteorological data, Daifuji Maru, June 28–October 1, 1956*, 83 pp., 1957 (processed).

Stroup, E. D., Mid-Pacific oceanography, pt 4, transequatorial waters, Jaunary–March, 1952, *U. S. Fish Wildlife Serv. Spec. Sci. Rep. Fisher. 135*, 52 pp., 18 fig., 1954.

Suda, K., *EQUAPAC oceanographic and meteorological data (preliminary report)*, Japanese Hydrographic Office, 52 pp., 1957 (processed).

Sverdrup, H. U., M. W. Johnson, and R. H. Fleming, *The oceans, their physics, chemistry, and general biology*, Prentice-Hall, 1087 pp., 1942.

Thomsen, H., Hydrographical observations made during the *Dana* expedition, 1928–30, *Dana Report 12*, 46 pp., 1937.

Wilson, R. C., and M. O. Rinkel, Marquesas area oceanographic and fishery data, January–March 1957, *U. S. Fish Wildlife Serv. Spec. Sci. Rep. Fisher. 238*, 136 pp., 1957.

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RELATIONSHIP BETWEEN SECCHI DISC READINGS AND LIGHT PENETRATION IN LAKE HURON

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ABSTRACT

Fifty-seven paired photometer and Secchi disc measurements made at 18 stations in Saginaw Bay and Lake Huron support the view that a counterclockwise current usually occurs in the Bay with more transparent Lake Huron water flowing in along the northwest shore and less transparent Bay water flowing out along the southeast shore. The average percentage transmission of surface light intensity, at the Secchi disc depth, was 14.7 percent. Discrepancies in the relationship of disc readings to percentage transmission of surface light are related to the condition of the sky and sea. It is suggested that these discrepancies can best be explained on the basis of the spectral sensitivity of the human eye and its response to surface glare.

INTRODUCTION

The importance of light as an environmental factor can scarcely be overemphasized since it is the basis for almost all biological activity in water. The distribution and production of phytoplankton are directly related to the quantity of radiant energy penetrating the water. The abundance of phytoplankton in turn affects the distribution and production of zooplankton, and ultimately the production of fish. Light also directly influences the distribution of these organisms. In spite of its importance, very little information is available on the penetration of light into the waters of the Great Lakes. Some data have been published on Lake Erie (Parmenter, 1929; Chandler, 1942; Wright, 1955; Verduin, 1956), Lake Huron (Ayers, Anderson, Chandler, and Lauff, 1956), and Lake Michigan (Lauff, 1957). Only Chandler's study dealt with photometer measurements; the other studies were based on Secchi disc readings. For this reason, it was considered highly desirable to be able to interpret the value of Secchi disc readings in terms of light transmission.

FIELD PROCEDURE

Light-penetration measurements were made in June-September 1956 at 18 stations established in the operation of the U. S. Fish and Wildlife Service research vessel *Cisco* (Fig. 1) in Lake Huron and Saginaw Bay. Four stations were in the Bay and 14 in Lake Huron proper. These stations were visited at intervals throughout the summer and 57 paired photometer and Secchi disc readings were made.

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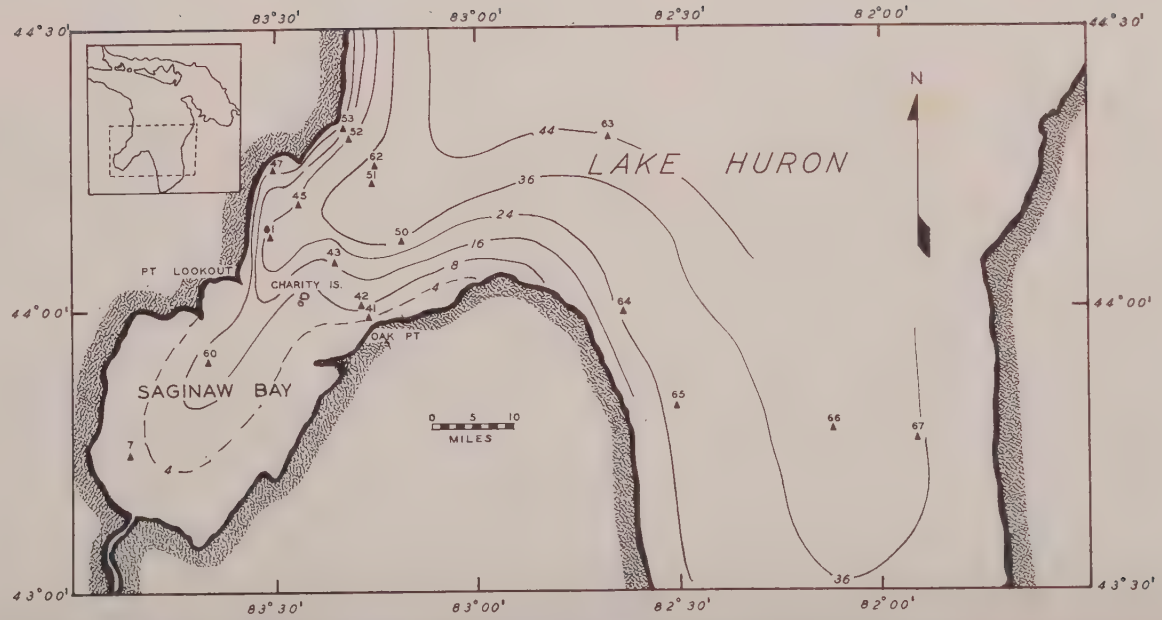

FIGURE 1.—Saginaw Bay and the adjacent section of Lake Huron showing principal stations and average Secchi disc transparency (feet) June-August, 1956.

In this study Saginaw Bay water has been separated from Lake Huron water by a line extending from Point Lookout to Charity Island and from the island to Oak Point (Fig. 1). Chemical and physical data collected at hydrographic stations east of this line indicate that Lake Huron water enters the mouth of the Bay, whereas similar data from areas west of Charity Island indicate that conditions there approach those of an eutrophic lake. Data presented by Ayers *et al.,* (1956) also show that Lake Huron water extends into the mouth of the Bay.

Transparency measurements were made with a standard Secchi disc (diameter 20 centimeters) with black and white quadrants. Light-penetration measurements were made with a pair of 856YR Photronic photoelectric cells, matched for output and linearity, and a model 622 Weston microammeter. Surface light intensity was measured with one photoelectric cell and subsurface intensity with the other. This photometer was calibrated by the Engineering Research Institute, University of Michigan, so that readings of each cell could be converted to foot-candles. Field data were obtained by determining the greatest depth at which the Secchi disc was visible, and then measuring the light intensity at that depth and at the surface with the photometer.

Transparency measurements within a single area were similar throughout the period of study. Therefore, average readings for the entire summer at each station were used in drawing an isopleth map (Fig. 1) to illustrate the general situation. Either circulation is stable in this area in June-September or most of the measurements were made when similar currents existed. A limited number of transparency measurements by Ayers *et al.,* (1956) showed a comparable distribution.

Transparency of Saginaw Bay Water

It has been postulated that the circulation in Saginaw Bay is estuarine and that inflow occurs along the northwest shore and outflow along the southeast shore (Ayers *et al.,* 1956). The close agreement in the average disc readings at stations 7 and 41 (4 feet at both stations) supports the view that outflow takes place along the southeast shore. Similarly, the occurrence of clearer water at station 60, where all readings except one (10 feet) were 8 feet, indicates the penetration of Lake Huron water along the northwest shore into this region. Lake Huron and Saginaw Bay waters evidently flow together and mix in the vicinity of stations 42, 43, 47, and 61. At these stations the transparency varied considerably throughout the summer, ranging from 7 to 24 feet in July (average 16.8 feet) and from 9 to 32 feet during August (average 19.6 feet).

Transparency of Lake Huron Water

In the latter part of June and in mid-July, the Secchi disc readings averaged 29.3 and 29.5 feet, respectively, in open-lake area (range, 15 to

42 feet). Transparency increased notably at all open-lake stations in August, averaging 35.7 feet and ranging from 20 to 54 feet. A maximum disc reading of 54 feet was recorded at station 63. Low values (15 to 20 feet) in the open lake were frequently recorded from station 64. This exceptional situation may be due to a flow of Saginaw Bay water around the southeast shore into this area. Throughout the summer low transparency was also observed in north-shore waters at station 53 (5 to 13 feet).

Comparison of Secchi Disc and Photometer Readings

Photometer readings at the depth of the Secchi disc reading are expressed as percentage transmission of surface light. Secchi disc and photometer readings were made under various weather and sea conditions.

The average percentage transmission of surface light intensity, at the Secchi disc depth, was 14.7 percent, with a standard deviation of 3.95. This value compares favorably with those established by several other investigators. In the English Channel the Secchi disc disappeared from sight at a depth where the illumination was 15.8 percent of that at the surface (Poole and Atkins, 1929). Clarke (1941) published a value of 15.2 percent for the North Atlantic. Secchi disc readings have been found to be inversely proportional to attentuation coefficients which are about directly proportional to phytoplankton concentrations (Jones and Wils, 1956). Yoshimura (1938), using Birge and Juday's data, found that there was a linear relationship between the Secchi disc depth and the depth to which 5 percent of the surface light penetrated. The light penetration measurements were made with a pyrlimnometer, an instrument which is evidently less sensitive than photocells, since it recorded less light at Secchi disc depths than did the photocells.

The photometer measurements showed that more light was required to see the Secchi disc when the sea was calm than when the waves were gentle or choppy (Table 1). This relation held true regardless of sky conditions or the color characteristics of the water. The discrepancies were undoubtedly related to visual surface glare which was at a maximum when the sea was calm. Surface glare would cause the observer's pupils to contract, thereby

Table 1.—*Effect of state of sea on percentage transmission of light to maximum depth of visibility of Secchi disc.*

Sea	Number of observations	Percentage transmission	
		Average	Range
Calm	8	17.1	8.8–24.2
Gentle	36	14.9	8.5–22.6
Choppy	13	12.8	5.7–22.3
Total	57	14.7	5.7–24.2

limiting the amount of light entering his eyes and making it more difficult to see the Secchi disc. Surface glare had little or no influence, however, on the photometer measurements, since it has been shown that the surface loss of light, as measured by photocells, is substantially the same for smooth or rough surfaces when the sun has a zenith angle[1] of less than 50° (Davis, 1941). All measurements of this study were made when the zenith angle was less than 50°.

There was some evidence that the Secchi disc could be seen to a greater depth on clear days than on cloudy days, but differences in the measurements were slight. Consequently these data have not been included.

In the curve depicting the percentage transmission of light at the point of Secchi-disc extinction (Fig. 2), the shallowest readings were made in the Bay and the deepest in Lake Huron proper. Values falling between these extremes were mostly from areas where mixing of lake and bay water occurred. The trend in the curve is probably determined by the differences between the spectral sensitivity of the human eye and the photoelectric cell, and by the wave band of light that penetrated to the disc depth. Preliminary analysis of our light-penetration data indicates that green light (490 mu to 540 mu) penetrated to the greatest depth in Lake Huron, whereas yellow-orange light (590 mu to 610 mu) penetrated to a greater depth than green light in Saginaw Bay. Scattering of blue and green light was greater in the Bay than in Lake Huron because of the greater concentrations of suspended matter. The lower part of the curve (Fig. 2) shows that the Secchi disc could be seen at a depth to which a relatively small quantity of light penetrated in Lake Huron. Theoretically, the eye should discern the Secchi disc most easily in waters having a peak transmission of light with a wave-length of 550 mu, a value close to that of light penetrating the deeper areas of Lake Huron. Disc readings made in the Bay and especially in areas of mixing were low although the photometer indicated that more light was present than was required to see the disc at greater depths in the open lake. The human eye has less sensitivity to the yellow-orange light that penetrates into this water. The deflection of the upper part of the curve to the left is probably due to the increased ability of the observer to detect the disc at very shallow depths.

Sauberer (1939) also observed that there was a greater percentage of the surface light at the Secchi disc depth in turbid water than in clearer water. He explained this by postulating that the suspended material in turbid water caused a diffused light and an increase in the light scattered up from lower levels, consequently the Secchi disc could not be as easily seen. There is some doubt, however, as to whether light scattered up from below the disc is of any consequence.

Different individuals did not agree on disc readings at the same station. Discrepancies as great as 2 feet occurred between observations by different

[1] The sun has a zenith angle of 0° when directly overhead.

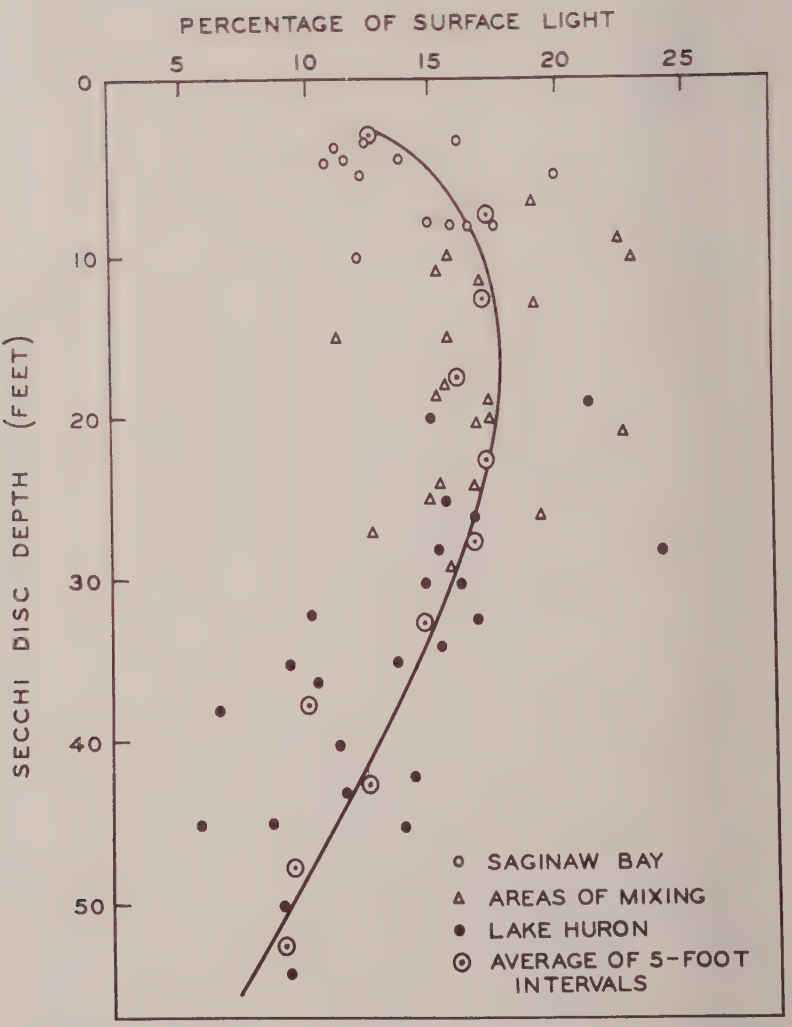

FIGURE 2.—Relationship of Secchi disc readings (feet) to percentage transmission of surface light at that depth.

individuals in clearer waters. For this reason the Secchi disc readings were made by the same observer with but few exceptions. Distance above the water surface was also a factor; usually the observer could see the disc at depths up to 2 feet deeper when he moved closer to the water surface. During this study most of the observations were made the same distance above the water. When the sky was not overcast observations were made on the shady side of the boat.

The influence that all these factors exert upon the accuracy of Secchi-disc measurements indicates the need to know more about this widely used tool. A more intensive study is desirable to ascertain more precisely what disc readings mean in terms of actual light penetration.

Literature Cited

Ayers, J. C., D. V. Anderson, D. C. Chandler and G. H. Lauff
1956. Currents and water masses of Lake Huron. Great Lakes Res. Inst., Tech. paper No. 1., 101 pp.

Chandler, D. C.
1942. Limnological studies of western Lake Erie. II. Light penetration and its relation to turbidity. Ecol., Vol. 23, pp. 41-52.

Clarke, George L.
1941. Observations on transparency in the southwestern section of the North Atlantic Ocean. Jour. Mar. Res., Vol. 4, pp. 221-230.

Davis, Francis J.
1941. Surface loss of solar and sky radiation by inland lakes. Trans. Wis. Acad. Sci., Arts, and Lett., Vol. 33, pp. 83-93.

Jones, D., and M. S. Wils
1956. The attenuation of light in sea and estuarine waters in relation to the concentration of suspended solid matter. Jour. Mar. Biol. Assoc. U.K., Vol. 35, pp. 431-444.

Lauff, George H.
1957. The physical limnology of Grand Traverse Bay. Great Lakes Res. Inst., Publ. No. 2, 56 pp.

Parmenter, Richard
1929. Hydrography of Lake Erie. Bull. Buffalo Soc. Nat. Sci., Vol. 14, pp. 25-49.

Poole, H. H., and W. R. G. Atkins
1929. Photo-electric measurements of submarine illumination throughout the year. Jour. Mar. Biol. Assoc. U.K., Vol. 16, pp. 297-324.

Sauberer, F.
1939. Beiträge zur Kenntnis des licktlimas einiger Alpenseen. Int. Rev. Hydrobiol., Vol. 39, pp. 20-55.

Verduin, Jacob
1956. Primary production in lakes. Limnol. and Oceanogr., Vol. 1, pp. 85-91.

Wright, Stillman
1955. Limnological survey of western Lake Erie. U.S. Fish and Wildlife Serv., Spec. Sci. Rep.: Fish. No. 139, 341 pp.

Yoshimura, Shinkichi
1938. Dissolved oxygen of the lake waters of Japan. Sci. Rep. Tokyo Bunrika Daigaku, Sect. C, Vol. 2, pp. 63-277.

RESEARCH NOTE

Additions to the Fishes Known from the Vicinity of Cedar Key, Florida

Two species of the family Carangidae are added to the list of fishes known from the vicinity of Cedar Key, Florida (Reid, 1954, Bull. Mar. Sci. Gulf & Caribb., 4(1) : 1-94. Caldwell, 1954, Quart. Jour. Fla. Acad. Sci., 17(3) : 182-184. Caldwell, 1955, *Ibid,* 18(1) : 48. Caldwell, 1957, *Ibid,* 20(2) : 126-128. Kilby, 1955, Tulane Stud. Zool., 2(8) : 175-247). These specimens are in the collections of the U. S. Fish and Wildlife Service's South Atlantic Fishery Investigations at Brunswick, Georgia.

Caranx ruber (Bloch). Jack crevalle or green jack. Two specimens, 129 and 137 mm. in standard length, were taken by the U. S. Fish and Wildlife Service M/V *Silver Bay,* Station 152, 29°01′ N., 83°21′ W., approximately 11 miles southwest of Cedar Key, August 21, 1957. This species has only rarely been reported from the northern Gulf of Mexico (Berry, MS, Fish. Bull. Fish & Wildl. Serv.).

Seriola dumerili (Risso). Great amberjack. One specimen, 150 mm. in standard length, was taken at *Silver Bay* Station 152 (data as above). Another, 250 mm. in standard length, was caught at Seahorse Reef, October 12, 1957, by Dr. E. Lowe Pierce, University of Florida. These identifications are based on the descriptions of Ginsburg (1952, Pub. Inst. Mar. Sci., 2(2) : 43-117). The nuchal band is vaguely visible on the 150-mm. specimen and extends from over the eye to the origin of the first dorsal fin; but it is not present on the 250-mm. specimen. The great amberjack is relatively common in the Gulf of Mexico, and visual accounts of amberjacks of over six feet in total length are probably attributable to this species.—Frederick H. Berry, U. S. Fish and Wildlife Service, Brunswick, Ga.

[illegible] Quart. Jour. Fla. Acad. Sci., 20(4), 1957.

1958. Quart. Jour. Fla. Acad. Sci. (1957), 20(4): 232.

Contribution No. 20
U. S. Fish & Wildlife Service
Bureau of Commercial Fisheries
Biological Laboratory
Brunswick, Georgia

Research Note

ADDITIONS TO THE FISHES OF CEDAR KEY, FLORIDA, AND A LIST OF GULF OF MEXICO CARANGIDAE

Two species are added to the list of fishes known from the vicinity of Cedar Key, Florida (Reid, 1954, Bull. Mar. Sci. Gulf & Carib., 4(1): 1-94. Kilby, 1955, Tulane Stud. Zool., 2(8): 175-247. Caldwell, 1954, Quart. Jour. Fla. Acad Sci., 17(3): 182-184. Caldwell, 1955, *Ibid.*, 18(1): 48. Caldwell, 1957, *Ibid.*, 20(2): 126-128. Berry, 1958, *Ibid.*, (1957), 20(4): 232.)

Seriola zonata (Mitchill). Banded rudderfish. A specimen, 165 mm. in standard length, was caught 8 miles off Cedar Key on May 24, 1958, by Dr. R. E. Page and loaned to me by Dr. E. Lowe Pierce, both of the University of Florida.

Following the work of Ginsburg (1952, Pub. Inst. Mar. Sci., 2(2): 43-117) and my own investigations, the following 26 species of the family Carangidae are known to have been taken from the Gulf of Mexico, with the 11 species that have now been recorded from the Cedar Key area prefixed by an asterisk: **Oligoplites saurus* (Bloch and Schneider), *Naucrates ductor* (Linnaeus), *Elagatis bipinnulatus* (Quoy and Gaimard), **Seriola zonata* (Mitchill), **Seriola dumerili* (Risso), *Seriola fasciata* (Bloch), *Seriola falcata* Cuvier, **Trachinotus carolinus* (Linnaeus), **Trachinotus falcatus* (Linnaeus), *Trachinotus glaucus* (Bloch), **(Chloroscombrus chrysurus* (Linnaeus), **Caranx crysos* (Mitchill), **Caranx ruber* (Bloch), *Caranx bartholomaei* Cuvier, *Caranx latus* Agassiz, **Caranx hippos* (Linnaeus), *Caranx lugubris* Poey, *Hemicaranx amblyrhynchus* (Cuvier), *Hemicaranx fasciatus* (Cuvier), *Uraspis heidi* Fowler, *Selar crumenophthalmus* (Bloch), *Decapterus punctatus* (Agassiz), *Trachurus lathami* Nichols, **Vomer setapinnis* (Mitchill), **Selene vomer* (Linnaeus), *Alectis crinitus* (Mitchill).

Lagocephalus laevigatus (Linnaeus). Smooth puffer. A specimen, 310 mm. in standard length, was caught by Dr. Pierce off Cedar Key in June, 1958, and was brought to my attention by Dr. Daniel M. Cohen of the University of Florida. Schultz (1949, Proc. U. S. Nat. Mus., 99(3235): 197) considered *L. pachycephalus* (Ranzani), which has also been recorded from the northern Gulf of Mexico, to be a synonym of *L. laevigatus*.

In his list of Florida fishes Briggs (1958, Bull. Fla. State Mus., Biol. Sci., 2(8): 223-318) indicated that about 550 species of shore fishes occur on the west coast of Florida from the southern Florida Keys to Alabama. Approximately 135 of these have not been reported north of the Florida Keys; therefore, about 415 species of shore fishes have been recorded from West Florida north of the Florida Keys; to date, 149 species from 66 families have been recorded from the Cedar Key vicinity.—FREDERICK H. BERRY, U. S. Fish and Wildlife Service, Brunswick, Georgia.

Quart. Journ. Fla. Acad. Sci., 21(2), 1958.

Contribution No. 29
U. S. Fish & Wildlife Service
Bureau of Commercial Fisheries
Biological Laboratory
Brunswick, Georgia

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A New Species of Fish from the Western North Atlantic, *Dikellorhynchus tropidolepis*, and Relationships of the Genera *Dikellorhynchus* and *Malacanthus*

Frederick H. Berry

THREE extraordinary specimens taken from the stomach of a dolphin, *Coryphaena hippurus* Linnaeus, represent a previously undescribed form. The three, 55, 56.5, and 60 mm. in standard length, were identified as *Malacanthus plumieri* (Bloch)

Contribution No. 14
U. S. Fish & Wildlife Service
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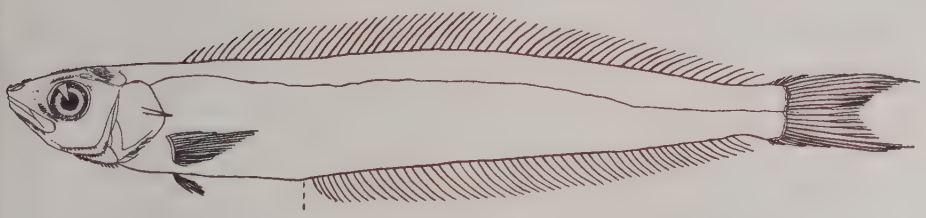


Fig. 1. *Dikellorhynchus tropidolepis,* holotype, 56.5 mm. in standard length, USNM 158376.

(in Anderson, Gehringer, and Cohen, 1956: 54) because of the apparent similarity of major morphological and meristic characters. They were considered worthy of published description and illustration because of the presence of keeled scales and multiple spines and serrations on the head, not present on adult *M. plumieri.* Then my attention was directed to a grossly similar form from South Africa, described as a new genus and species, *Dikellorhynchus incredibilis,* by Smith (1956). Smith's specimen was about 60 mm. in standard length, and, although he judged it to be a new species, he suggested that it might represent a hitherto unknown juvenile stage of *Malacanthus hoedtii* Bleeker of the Indo-pacific. The three specimens were compared with a U. S. National Museum specimen of *M. plumieri,* 55.5 mm. in standard length, which is probably that discussed by Longley and Hildebrand (1941: 145), although it differs in some proportions and counts from that description and has canine teeth. In contrast to my three specimens, this fish lacks head spines and serrations and keeled scales. These and other differences suggest that the fish here described are specifically distinct from *M. plumieri.*

I am most grateful to Mr. William W. Anderson, Mr. Jack W. Gehringer, Mr. Hugh M. Fields, and Dr. Giles W. Mead, U. S. Fish and Wildlife Service, to Dr. John C. Briggs, University of Florida, to Dr. Robert R. Miller, University of Michigan, and to Dr. William A. Gosline, University of Hawaii, for propitious suggestions; to Dr. J. L. B. Smith, Rhodes University, for information on the type of *D. incredibilis;* and to Dr. Leonard P. Schultz, U. S. National Museum, Dr. James E. Böhlke, Academy of Natural Sciences of Philadelphia, and Mr. E. Milby Burton, Charleston Museum, for the loan of specimens.

Dikellorhynchus tropidolepis, *sp. nov.*

Figures 1–6

Diagnosis: A *Dikellorhynchus* (Smith, 1956) with a rostral process bearing 2 pairs of lateral spines, a forked tail, and the body with keeled scales possessing 0 to 3 ctenii. Cheeks and opercles scaled. Dorsal IV or V-54 or 55. Anal I-51 to 53. Pectoral 16 or 17. Pelvic I-5. Gillrakers 3 or 4 + 1 + 8. Head 23.0 (22.9 to 24.2); depth at pectoral 15.0 (16.0

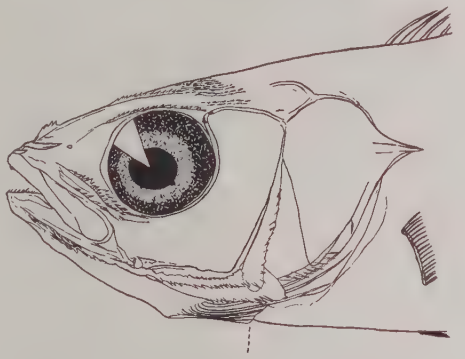


Fig. 2. Lateral view of head of *Dikellorhynchus tropidolepis,* 60.0 mm. in standard length.

Fig. 3. Dorsal view of head of *Dikellorhynchus tropidolepis,* 60.0 mm. in standard length.

Fig. 4. Top view of scale taken from below lateral line on caudal peduncle of 60-mm. *Dikellorhynchus tropidolepis.*

to 14.8); snout to anal origin 40.0 (42.0 to 39.6) (in percent of standard length).

Description: Body elongate and slightly compressed. Snout moderately pointed. Lower jaw included. Two pairs of laterally extended rostral spines, the posterior pair the larger. Both pairs of spines lie over the snout at 60 mm. in standard length (S.L.), the anterior pair slightly projecting beyond the snout at 56.5 mm. S.L., and the anterior pair broken off and missing from the 55-mm. S.L. specimen, but apparently would have projected more in advance of the snout. A pair of elevated ridges, bearing four strong serrations, attached to the same rostral process as the rostral spines and located immediately behind them. A second less elevated pair of ridges originate just posterior to the pair described above and extend on top of the head to about the posterior margin of the pupil, and are serrated on that portion over the eye. A similar serrated ridge over each eye. A series of about 12 to 14 low, close-set, and generally parallel ridges on each side of top of head. Two similar ridges with stronger serrations separated from the most lateral of these on each side. Two parallel rows of strongly serrated ridges over the maxillary with a shorter row above the posterior portion of these. These 3 ridges apparently converge under the eye to become continuous with the ventral circumorgitals. A small group of strong serrations is located on the circumorbital bone near the anterio-dorsal margin of the preoperculum. Two parallel rows of serrated ridges on underside of each mandible. Opercle ending in a single strong spine. Spines on posterior and ventral margins of preoperculum and a row of smaller spines above these on the ventral margin. Spines on suboperculum and lower edge of operculum.

Gill membranes united on a vertical with angle of preoperculum. Gillrakers widely spaced, the one at the angle shorted and thinner than those adjacent.

Maxillary ending below front of eye. Teeth in upper jaw: At the front of each half of the jaw near the symphysis is a large recurved canine, a group of about 10 recurved canines behind this, and a patch of smaller canines behind these. From this anterior group of teeth and extending around each half of the jaw is a series of large canine teeth interspersed with smaller ones—the larger canines of this lateral series are smaller than the large canines of the frontal group. Teeth in lower jaw: At the front of each half of the jaw is a group of recurved canines of different sizes with the larger ones anterior. A single row of canines extends around each half of the jaw from this frontal group—these are of varying sizes, and the 4th, 5th, or 6th canine in this row is the largest in the jaw. The posterior canines of the lower jaw are larger than the corresponding ones of the upper jaw, but the canines in the frontal group are smaller than those of the frontal group of the upper jaw. The palate is edentate.

The dorsal fin is continuous. The first 4 or 5 elements of the dorsal fin and the first element of the anal fin are slender, flexible spines, and are shorter than the following soft-rays. The caudal is forked with all but the single most dorsal and most ventral principal rays branched. The pectoral and pelvic fins are inserted on an approximate vertical of the tip of the opercular spine and the dorsal fin origin. The first ray of the pectoral is unbranched; the others all appear to be branched. The spine of the pelvic is strong and all the pelvic soft-rays are branched. (Most of the fin rays are damaged or broken.)

Most of the scales are missing from the three specimens, but the scale pockets are easily discernible. They cover the cheeks forward to the mandibles, and the opercles. Scale pockets begin on top of the head directly behind the two groups of close-set serrated ridges and continue backward onto the caudal fin to about half-way between the caudal base and the fork of the tail, covering all the body except small scaleless areas under the insertion of the pelvics and behind the insertion of the pectorals. The paired fins and the dorsal and anal fins are apparently not scaled.

The scales have an oblique arrangement directed posterio-ventrally. The lateral line extends sinuously along the upper portion of the body from the cleithrum to under about the 40th dorsal ray, gradually descends to the midline of the body under about the 50th dorsal ray, and continues relatively straight onto the caudal fin to about two-fifths of the distance from the caudal base to the fork. No pores have developed in the lateral line scales, and each of these scales bears two keel-like structures which extend beyond a curved notch in the posterior margin of the scale base.

The scales are barely imbricated. Scales near the peduncle have three large ctenii (Fig. 4); scales over the major portion of the body have only one (Figs. 5 and 6); and a few scales that remained on the jugular region

had none—no scales remained on the head. Each scale has a thin keel set at a right angle to the base and inserted from the focus (or the point of convergence of the radii) to the insertion of the ctenii. The keels extend posteriorly above the ctenii (when present), and each keel has from one to three large serrations posteriorly on the top margin. Circuli are well formed only on the anterior portion of the scale, and from one to 6 partially or completely formed radii may be present.

There are 10 abdominal and 14 caudal vertebrae. The abdominal cavity extends to beneath the junction of the 9th and 10th abdominal vertebrae. The anus is situated nearly below the junction of the 6th and 7th vertebrae. The anal fin extends forward to beneath the junction of the 7th and 8th vertebrae.

The only pigmentation remaining on the 3 specimens consists of many small pigment spots on the brain (visible through the transparent skull in the area of the two groups of close-set serrated ridges).

Relationship: With respect to certain distinctive characters regarded to be of generic value this species is most closely related to *Dikellorhynchus incredibilis* Smith. These are the presence of rostral spines, close-set or laminate bony ridges on top of the head, serrated bony ridges on the head, preopercular spines, gill membranes united far forward, and keeled scales. Each of these characters serves to distinguish the genus *Dikellorhynchus* from *Malacanthus*. Another difference in the two genera is that the pectorals of *Dikellorhynchus* are inserted lower on the body and their tips do not extend back over the anal fin as they do in *Malacanthus*.

The scales of *D. tropidolepis* have 0 to 3 ctenii. Dr. Smith has written (personal communication) that a few of the scales of the type of *D. incredibilis* have a single posterior spicule at the scale base and some of the keels have 3 points similar to those in Figure 6.

The major characters that distinguish the two species of *Dikellorhynchus* are: 1) Lateral rostral spines, *D. tropidolepis* with two pairs, the anterior pair either slightly or not protruding beyond tip of premaxillary and *D. incredibilis* with one pair definitely protruding; 2) Cheek and operculum, scaled on *D. tropidolepis* and not scaled on *D. incredibilis*; 3) Spiny or serrated ridges on top and sides of head, converge toward but not to above snout on *D. tropidolepis* and converge to above snout on *D. incredibilis*; and 4) Caudal fin, forked on *D. tropidolepis* and rounded on *D. incredibilis*. By considering these 4 differences to be only of specific magnitude, an expansion of the generic characters of the genus is necessary for Smith had limited *Dikellorhynchus* in part by these characters. This combination of differences between the two species is not considered to warrant generic separation for reasons discussed later.

The single specimen of *D. incredibilis* was found on the beach after an onset of cold water, and Smith (1956: 57) suggested that it might live "at some depth, possibly in the 'Berycid' Zone." The dolphin stomach that contained the *D. tropidolepis* specimens also

Fig. 5. Top view of scale taken from above lateral line and below about thirtieth dorsal ray of 60 mm. *Dikellorhynchus tropidolepis*.

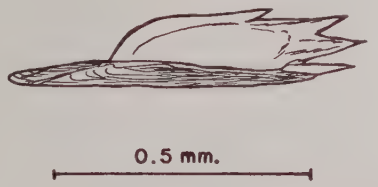


Fig. 6. Side view of scale taken from above lateral line and below about thirtieth dorsal ray of 60 mm. *Dikellorhynchus tropidolepis* (same scale as shown in figure 5).

contained larval or juvenile forms of species of *Holocentrus, Coryphaena, Xiphias, Dactylopterus, Gempylus, Sphaeroides,* and *Ophioblennius* (Anderson, Gehringer, and Cohen 1956: 54). Since these forms generally occur in pelagic surface waters where dolphin are known to feed, it is possible that *D. tropidolepis* is pelagic.

Holotype: USNM 158376; 56.5 mm. in standard length from the stomach of a dolphin, *Coryphaena hippurus,* which was caught by surface trolling during Cruise 2 of the M/V *Theodore N. Gill* for the U. S. Fish and Wildlife Service's South Atlantic Fishery Investigations, at approximately 34°28.5′ N., 74°38.5′ W., about 96 miles east of Cape Lookout Light, N. C., over a depth of 1800 fathoms, May 12, 1953.

Paratypes: USNM 158377, one specimen 60 mm. in standard length; and South Atlantic Fishery Investigations collection, one specimen 55 mm. in standard length; both taken with the holotype; partially cleared with 3 percent potassium hydroxide, stained with alizarine dye, and preserved in glycerine.

Derivation of the name: From the Greek *tropidos,* a keel, and *lepis,* a scale, in reference to the unique keeled scales.

Key to the genera of Malacanthidae (including Latilidae) of the Western North Atlantic

A. Total elements (spines and soft-rays) in dorsal fin 36 or less and in anal fin 27 or less. Vertebrae more than 24 ..... (Branchiostegidae, Latilidae)

B. Total elements in dorsal fin about 22 and anal fin about 14 to 15. Adipose appendage at nape ..... *Lopholatilus* Goode and Bean 1879

BB. Total elements in dorsal fin 29 to 36 and in anal fin 21 to 27. No adipose appendage at nape ..... *Caulolatilus* Gill 1862

AA. Total elements (spines and soft-rays) in dorsal fin 47 or more and in anal fin 39 or more. Vertebrae 24 ..... (Malacanthidae)

C. Total elements in dorsal fin 47 to 62 and in anal fin 39 to 54 ..... *Dikellorhynchus* Smith 1956, *Malacanthus* Cuvier 1829

Key to the Species of *Dikellorhynchus* and *Malacanthus*

A. Rostral spines present. Multiple spines on opercular bones in addition to large spine on operculum. Serrations on many bones of head. Scales keeled. Gill membranes connected on a vertical with angle of preoperculum ..... *Dikellorhynchus*

B. One pair of rostral spines. Caudal fin rounded ..... *D. incredibilis* (Indian Ocean)

BB. Two pairs of rostral spines. Caudal fin forked ..... *D. tropidolepis* (Western North Atlantic Ocean)

AA. No rostral spines. One strong spine on operculum; none on other opercular bones. No serrations on head. No keels on scales. Gill membranes connected posterior to a vertical with angle of preoperculum ... *Malacanthus*

C. Total number of elements (spines and soft-rays) in dorsal fin 52 or less and in anal fin 42 or less ..... *M. latovittatus* (Pacific and Indian Oceans)

CC. Total number of elements in dorsal fin 58 or more and in anal fin 49 or more

D. Caudal fin truncate. Two horizontal stripes on caudal. Head less than 22 percent of standard length ..... *M. hoedtii* (Pacific and Indian Oceans)

DD. Caudal fin forked or falcate. A single horizontally elongated spot on dorsal half of caudal near base. Head more than 24 percent of standard length ..... *M. plumieri* (Atlantic Ocean)

Comparison of the Species of *Dikellorhynchus* and *Malacanthus*

The genus *Malacanthus* is recognized as containing 3 species. Two of these, *M. hoedtii* and *M. latovittatus,* are Indo-Pacific forms and have been differentiated and described by Herre (1926: 220).

M. latovittatus has an elongated snout (Smith, 1950: pl. 13, fig. 384, and Weber and de Beaufort, 1936: fig. 105) similar to that of *M. plumieri* and contrasting with the shorter snout of *M. hoedtii.* The ranges of dorsal rays, IV to VI-43 to 46, and of anal rays, I-38 to 41, however, completely separate *M. latovittatus* from the other two species. It has been identified from Polynesia, Melanesia, and Indonesia, the Philippines (Weber and de Beaufort, 1936: 552) and west and south in the Indian Ocean to Inhaca Island (Smith, 1955: 6). Because of the above meristic separation, *M. latovittatus* does not further concern the relationships of the specimens of *Dikellorhynchus* and the other two species of *Malacanthus.*

M. hoedtii (Fig. 7) has been identified from the Hawaiian Islands, Micronesia, and the Philippines, Melanesia and New Zealand, Indonesia, (Weber and de Beaufort, 1936: 550), and west and south in the Indian Ocean to Madagascar and Bazaruto Bay (Smith, 1955: 6).

M. plumieri (Figs. 8, 12, and 13) has been reported from Bermuda (Bean, 1906: 83 and Beebe and Tee-Van, 1933: 172), on edge of Gulf Stream off Charleston, S. C., and Key West, Fla. (Fowler, 1945: 213 and 312), Tortugas, Fla. (Longley and Hildebrand, 1941: 145), Port Isabel and Port Aransas, Texas (Baughman, 1947: 280 and 1950: 251), *Oregon* Sta. 591, 23°24′ N., 87°09′ W., on Campeche Bank and *Oregon* Sta. 788, 23°37′ N., 84°30′ W., northwest of Cuba (Springer and Bullis, 1956: 88), *Oregon* Sta. 1046, 22°40′ N., 91°42′ W., Cay Arenas (Mr. David K. Caldwell, personal communication and photograph), about 25 mi. south of Pensacola, Fla. (personal record), the Bahamas (Fowler, 1919: 151 and Parr, 1930: 67), Cuba (Jordan and Evermann, 1898: 2275), Cay Sal Bank (Breder, 1927: 84), Haiti (Fowler, 1937: 313), Jamaica (Fowler, 1939: 15), St. Croix (Blosser, 1909: 300 and Nichols, 1930: 371), Dutch West Indies (Metzelaar, 1919: 70), Roncador Bank, St. Andrews Island, and New Providence Island (Fowler, 1944: 89, 154, and 447), Brazil (Fowler, 1941: 169, see synonymy), and As-

cension Island (Norman, 1935: 56). Mr. G. Palmer reported (personal communication) that there are two specimens of *M. plumieri,* 347 and 468 mm. in standard length, from Ascension in the British Museum (Natural History).

The data in Table I were compiled from the published account of *D. incredibilis* (Smith, 1956) and personal communication on the type from Dr. Smith; notes were furnished by Mr. E. M. Burton of the Charleston Museum on the largest recorded specimen of *M. plumieri,* taken by fishing smack Osprey, from ESE of Charleston, S. C., in 27–30 fathoms, Sept. 25, 1950, 560 mm. S.L. (685 mm. total length, specimen not preserved); and from examination of the following specimens: *D. tropidolepis,* the holotype and paratypes. *M. hoedtii,* ANSP 28025, Hawaiian I., 164 mm. S.L.; ANSP 28166-7, Hawaiian I., 195 and 203 mm. S.L.; ANSP 29730-1, Honolulu, Hawaiian I., 197 and 252 mm. S. L. *M. plumieri,* USNM 116836, Tortugas, Fla., collector W. H. Longley, 55.5 mm. S.L.; USNM 9819, Cuba, collector Poey, 174 mm. S.L.; USNM 123657, off Havana, Cuba, Nov. 4, 1945, collector L. R. Rivas, 198 mm. S.L.; South Atlantic Fishery Investigations specimen, caught bait-fishing on bottom, about 25 mi. south of Pensacola, Fla., in about 25 fathoms, by Mr. Broyles Yon, Oct. 3, 1955, 405 mm. S.L.; ChM 38.85, taken by fishing smack Harold, 60 mi. ESE of Charleston, S. C., April 30, 1938, 505 mm. S.L.

Certain morphometric growth changes in *M. plumieri* are evident from comparison of Figures 8, 12, and 13 and from Table I. From the smallest to the largest sizes examined, relative to body (standard) length: The pectorals increase, then decrease in length. The caudal fin becomes very falcate, then becomes less so. The eye diameter decreases. The snout length increases. The body depth (greatest) increases.

The only meristic change in *M. plumieri* with increase in body size is a decrease in number of the lower limb gillrakers—apparently the rakers tend to degenerate from the origin of the lower limb toward the angle.

A few characters of this group warrant clarification: All of the scales of *M. plumieri* and *M. hoedtii* do not possess ctenii—those anterior to a diagonal encircling the body from the dorsal fin origin to the anal fin origin are essentially cycloid, and the scales of *D. tropidolepis* are generally similar. There are small scaleless areas behind the pectoral and pelvic fins in these three species. The first element of the anal fin of these three species is a flexible spine. The anterior 4 or 5 elements of the dorsal fin of *D. tropidolepis* and the first 5 (possibly 4 to 6) elements of *M. plumieri* are flexible spines; but on specimens of *M. hoedtii* examined, only the first 2 elements of the dorsal fin are spines (this latter is contrary to all published accounts I have reviewed).

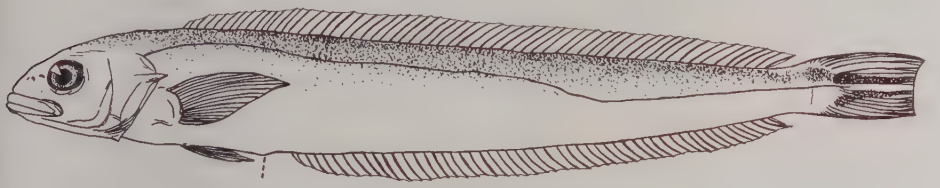


Fig. 7. *Malacanthus hoedtii,* 167 mm. in standard length.

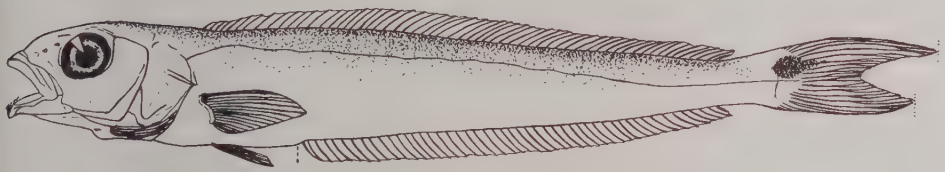


Fig. 8. *Malacanthus plumieri,* 55.5 mm. in standard length.

Relationships of the 4 species concerned can be drawn for morphometric and meristic characters in Table I.

The similarities of *D. tropidolepis* and *D. incredibilis* that separate them from *Malacanthus* species have been discussed. In one feature, the absence of scales on the cheeks and opercles, *D. incredibilis* is distinct from

the others. In many other characteristics, similarities of *D. tropidolepis* and *M. plumieri* are directly contrasted with similarities that relate *D. incredibilis* and *M. hoedtii*: *D. tropidolepis* and *M. plumieri* have longer head lengths, snout lengths, and snout to dorsal, anal, and paired fin insertions, and greater body depths than *D. incredibilis* and *M. hoedtii*. The forked tail of *D. tropidolepis* and the falcate tail of *M. plumieri* contrast with the rounded tail of *D. incredibilis* and truncate tail of *M. hoedtii*.

The scales of the 60 mm. *D. tropidolepis* (Fig. 5) and the 55.5 mm. *M. plumieri* (Fig. 11) are very similar in basic structure, except for the keel of *Dikellorhynchus*. The scales in the above two figures were taken from about the same position on each fish. The 5 ctenii on the *M. plumieri* scale, compared with only one ctenii on the *D. tropidolepis* scale, suggests that the scale of the former had developed to a further degree, since the number of ctenii increased on progressively larger sizes of *M. plumieri* (assuming a similar increase in number of ctenii with increase in body size in *D. tropidolepis*). As many as 141 ctenii and ctenii-bases were counted on a scale of the 505 mm. *M. plumieri* (curiously, not a single scale could be found on this fish that did not have a regenerated central portion).

The 3 specimens of *D. tropidolepis* were

TABLE I

MORPHOMETRIC AND MERISTIC VALUES OF SPECIMENS OF *Dikellorhynchus tropidolepis*, *Malacanthus plumieri*, *D. incredibilis*, AND *M. hoedtii*

[ASTERISKED ITEMS ARE APPROXIMATE VALUES]

	Dikellorhynchus tropidolepis	*Malacanthus plumieri*							*Dikellorhynchus incredibilis*	*Malacanthus hoedtii*				
Standard length, mm.	55.0	56.5	60.0	55.5	174	198	406	505	*59.8	164	195	197	203	252
Fork length, mm.	—	63.0	65.5	61.9	191	216	441	545	—	185	219	220	227	281
Total length, mm.	64.0	65.5	*69.5	*66.5	223	*236	490	600	70.0	187	221	224	228	283
Percent of Standard Length:														
Head length	22.9	23.0	24.2	25.2	24.7	25.5	25.9	27.3	20.5	21.3	21.3	21.1	21.4	21.0
Eye diameter	6.2	6.0	6.5	7.4	5.7	6.3	4.3	3.8	5.8	5.5	5.6	5.3	6.0	4.8
Snout length	5.6	5.8	6.3	7.0	9.8	9.7	12.2	13.8	5.7	6.4	6.7	6.9	6.2	6.7
Postorbital head length	11.1	10.8	11.2	11.0	9.8	10.1	10.5	10.8	8.8	9.8	10.0	10.2	10.1	9.9
Maxillary length	6.5	6.7	7.5	9.0	8.6	9.1	9.8	10.7	—	7.9	7.9	7.6	8.1	7.6
Dorsal base length	—	69.9	71.7	69.5	72.4	68.2	69.0	68.5	72.0	72.9	74.4	73.6	74.9	74.2
Anal base length	—	59.2	57.5	55.8	56.3	55.5	57.1	57.8	56.0	60.1	61.0	60.4	59.6	60.3
Pectoral length	11.6	*10.1	*10.7	12.6	13.5	14.4	12.8	11.7	9.0	14.6	14.4	14.5	15.5	*9.9
Pelvic length	*8.5	*7.4	*8.5	9.4	9.2	8.3	8.7	8.6	6.8	9.1	8.7	8.4	8.6	8.3
Snout to dorsal origin	22.9	22.3	21.2	25.0	23.6	25.3	24.1	25.7	22.0	22.0	22.6	21.6	20.9	21.2
Snout to anal origin	42.0	40.0	39.6	41.4	39.1	40.4	39.7	40.0	33.0	35.1	34.4	36.8	35.7	33.9
Snout to pectoral insertion	24.0	23.2	23.5	25.6	24.7	26.8	26.4	26.9	—	20.7	20.5	21.3	21.2	20.6
Snout to pelvic insertion	26.4	25.5	25.7	27.9	27.9	25.0	30.8	29.1	—	22.3	22.3	22.3	22.9	22.6
Head depth (through pupil)	—	10.4	12.8	14.1	12.4	11.8	13.1	14.5	—	11.6	11.0	9.6	10.3	11.3
Body depth (greatest)	—	15.4	15.3	15.5	15.2	*16.7	*15.5	18.0	12.4	14.6	15.6	14.7	*13.8	*14.7
Peduncle depth	—	6.5	6.0	6.5	6.3	6.3	6.8	6.8	4.0	5.6	5.4	5.3	5.2	5.6
Interorbital width (bony)	4.9	5.7	5.5	6.1	4.9	4.8	7.0	7.8	4.0	5.2	5.2	4.8	5.4	4.8
Body width (greatest)	—	10.3	11.5	8.6	9.c	*9.1	11.3	10.4	—	10.1	9.5	10.4	9.1	9.9
Dorsal	V-55	V-54	IV-55	V-54	V-56	V-55	V-57	V-57	(57)	II-58	II-58	II-58	II-59	II-56
Anal	I-53	I-52	I-51	I-48	I-51	I-50	I-53	I-53	(49)	I-52	I-52	I-51	I-51	I-49
Pectoral	17	*16	17	17	17	17	17	16	17	16	16	*16	16	16
Pelvic	I-5	I-5	I-5	I-5	I-5	I-5	I-5	I-5	I-5	I-5	I-5	I-5	I-5	I-5
Caudal: Principal	8 + 7	8 + 7	8 + 7	8 + 7	8 + 7	8 + 7	8 + 7	8 + 7	(15)	8 + 7	8 + 7	8 + 7	8 + 7	8 + 7
Secondary	11 + 11	—	13 + 12	—	—	—	—	—	—	—	—	—	—	—
Gill rakers: Upper	3	4	3	3	4	4	4	4	7	6	4	6	3	4
At angle	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Lower	8	8	8	8	6	6	5	3	11	9	*7	8	7 & 9	*7
Scales: Diagonal rows	—	*158	*142	*135	134	*139	150	144	115	*120	129	*125	132	129
In lateral line	—	—	*141	*155	142	*144	151	151	153	177	173	179	168	163
Branchiostegals	6	6	6	6	6	6	6	6	—	*6	6	*6	6	6

aken about 120 miles north of the known range of *M. plumieri*, and the type of *D. incredibilis* was obtained about 600 miles south of the recorded range of *M. hoedtii*. Both of these collection sites are in areas that are affected by currents that move away from areas where *Malacanthus* species are known to occur (the Gulf Stream in the Western Atlantic and the Agulhas Stream off Southwest Africa), and presumably the *Dikellorhynchus* specimens could have originated in waters where *Malacanthus* are known to occur.

Because only 4 specimens of *Dikellorhynchus* are known and all are about the same size, and because the early life history of *Malacanthus* is unknown, four suppositions may be projected to account for the relationships of the 2 genera: 1) That the *Dikellorhynchus* species are juvenile or adult forms as they have been described. 2) That the *Dikellorhynchus* specimens are larval forms of yet undescribed adults. 3) That the *Dikellorhynchus* specimens are aberrant growth stages of *M. plumieri* and *M. hoedtii*. 4) That *D. tropidolepis* and *D. incredibilis* are protracted larval stages of *M. plumieri* and *M. hoedtii*, respectively. These are discussed in order.

The first two of the above suppositions, assuming that *Dikellorhynchus* is a valid genus, have to be adopted in describing the specimens as new species. This seems logical in view of the spines and serrations on the head and the keeled scales of *Dikellorhynchus* and because of comparative sizes of the *Dikellorhynchus* specimens and of small *Malacanthus* specimens that have been ta-

Fig. 9. Lateral view of head of *Malacanthus plumieri*, 55.5 mm. in standard length.

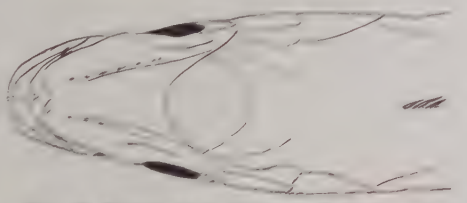
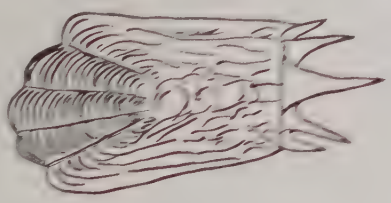


Fig. 10. Dorsal view of head of *Malacanthus plumieri*, 55.5 mm. in standard length.



0.5 mm.

Fig. 11. Left side of head [illegible] of *Malacanthus plumieri*, 10.5 mm. in standard length.

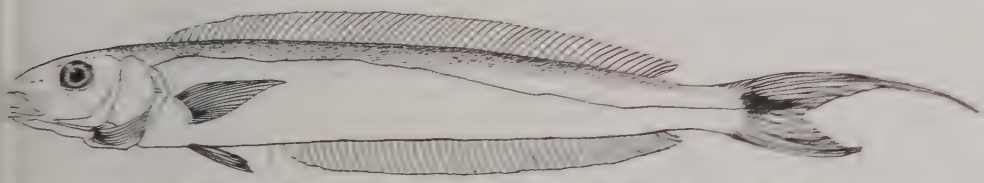


Fig. 12. *Malacanthus plumieri*, 78 mm. in standard length.

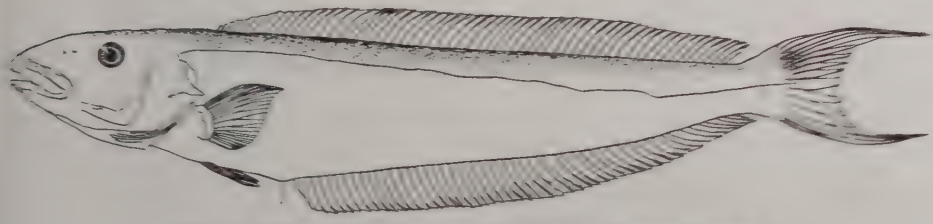


Fig. 13. *Malacanthus plumieri*, 505 mm. in standard length.

amined: The largest *D. tropidolepis* is larger than the smallest *M. plumieri* examined; and Dr. Smith has obtained a specimen of *M. hoedtii* 75 mm. in total length with very distinct parallel dark bars on the caudal (personal communication), which specimen is only 5 mm. longer in total length than the type of *D. incredibilis*. This is also supported by the more anterior joining of the gill membranes and the lower insertions of the pectorals of *Dikellorhynchus*. Smith (1956: 57) favored the first possibility, and expressed the opinion that his type was not a larval specimen. I believe the second of these two possibilities to be more tenable, primarily because of the posterior regression of the anterior pair of lateral rostral spines from 55 to 60 mm. S.L. in *D. tropidolepis* and because of the incompletely formed lateral line scales of this species.

The last two suppositions are suggested by the several characters that relate *D. tropidolepis* to *M. plumieri* and *D. incredibilis* to *M. hoedtii* and that thereby distinguish these two groups of separate geographic occurrence. This implies that *Dikellorhynchus* is only a growth stage of *Malacanthus*. The third of the above possibilities lacks substance when it is considered that 3 specimens of *D. tropidolepis*, all of slightly different sizes, were swallowed by one dolphin. The fourth possibility has a dual implication to the effect that all *Malacanthus* have a *Dikellorhynchus* stage in possessing head spines and serrations and keeled scales as larvae, and that the size of transformation from larva to juvenile may vary over an appreciable range of body size. There is precedence for the speculation that the transition from the larval to the juvenile form may be responsive to or dependent upon a change of environment, that the larva may continue to develop as such until the environmental change occurs, that this environmental change may occur at different times of development for individual fish, and, consequently, that the body size at transformation may vary greatly. Breder (1949: 296) described such a differential larval-juvenile transformation for *Acanthurus chirurgus* (Bloch) (= *A. hepatus* Linnaeus) in which he found the transparent "*pawnee*" larval stage specimens as large as 29 mm. in length and transformed juvenile specimens as small as 10 mm. in standard length. Breder inferred that the planktonic larval forms transformed when they reached a littoral habitat. *Malacanthus* species apparently inhabit the littoral zone of not too great depts. Beebe and Tee-Van (1933: 172), stating that the species is common in Bermuda, said it is found from close inshore on sand and grass to the deeper waters of 90 to 100 fathoms. The unknown larval forms of the species of *Malacanthus* may be pelagic *Dikellorhynchus* types.

The fourth supposition is the most intriguing to a student of fish development and cannot be entirely disregarded, but the second is the strongest on the basis of extant evidence and must be accepted until the early life histories of the species of *Dikellorhynchus* and *Malacanthus* become known.

Addendum—Additional specimens of *Dikellorhynchus tropidolepis* were found and identified after the manuscript was in galley. One entire specimen, 54 mm. in standard length; one specimen bitten apart, approximately 50 mm. S.L.; and the tail or trunk and tail portions of 13 others, from about 45 to 55 mm. S.L., were in the stomach contents of a *Coryphaena hippurus* taken by surface trolling during Cruise 5 of the Gill for the U. S. F. W. S. South Atlantic Fishery Investigations: taken at approximately 26°21′ N., 76°46′ W., about 16 miles northeast of Nassau, Bahamas, B. W. I., January 25, 1954. The specimens are in the collection of the South Atlantic Fishery Investigations. The anterior pair of rostral spines of the specimens of 54 and about 50 mm. S.L. are slightly more in advance of the snout than those of the 56.5-mm. paratype. The dolphin predator had other stomach contents consisting of exocoetid, scrombrid, and plectognath remains, fish eggs, crustaceans, and sargassum—which tend to indicate that it had been feeding near the surface.

Literature Cited

Anderson, William W., Jack W. Gehringer, and Edward Cohen. 1956. Physical oceanographic, biological, and chemical data, South Atlantic coast of the United States, *Theodore N. Gill* Cruise 2. *U. S. Fish and Wildl. Serv., Spec. Sci. Rept.: Fish. No. 198, p. 1–270, figs. 1–20.*

Baughman, J. L.
1947. Fishes not previously reported from Texas, with miscellaneous notes on other species. Copeia, *1947(4): 280.*
1950. Random notes on Texas fishes. Part II. *Texas Jour. Sci., 2(2): 242–63.*

Bean, Tarleton H. 1906. A catalogue of the fishes of Bermuda, with notes on a collection made in 1905 for the Field Museum. *Field Mus. Nat. Hist., Zool. Ser., 7(2): 21–89, figs. 1–14.*

Beebe, William and John Tee-Van. 1933. Field book of the shore fishes of Bermuda. *G. P. Putnam's Sons, N. Y., xiv + 337 p., text-figs. and pls.*

BLOSSER, CHRISTIAN B. 1909. Reports on the expedition to British Guiana of the Indiana University and the Carnegie Museum, 1908. Report No. 3. The marine fishes. *Ann. Carnegie Mus., 6(1): 295–300, pls. X–XII.*

BREDER, C. M., JR.
1927. Scientific results of the first oceanographic expedition of the "Pawnee," 1925. Fishes. *Bull. Bingham Oceanogr. Coll., 1(Art. 1): 1–90, figs. 1–36.*
1949. On the taxonomy and the postlarval stages of the surgeon-fish, *Acanthurus hepatus*. COPEIA, *1949(4): 296.*

FOWLER, HENRY W.
1919. Notes on tropical American fishes. *Proc. Acad. Nat. Sci. Phila., 71: 128–55.*
1937. A collection of Haytian fishes obtained by Mr. Stanley Woodward. *Proc. Acad. Nat. Sci. Phila. 89: 309–15, 1 fig.*
1939. Notes on fishes from Jamaica with descriptions of three new species. *Notulae Naturae, No. 35, p. 1–16, figs. 1–6.*
1941. A list of the fishes known from the coast of Brazil. *Arquiv. Zool. Sao Paulo, 3(Art. 6): 115–184.*
1944. Results of the fifth George Vanderbilt Expedition (1941). The fishes. *Monogr. Acad. Nat. Sci. Phila., No. 6, p. 57–583, figs. 1–268, pls. 1–20.*
1945. A study of the fishes of the Southern Piedmont and Coastal Plain. *Monogr. Acad. Nat. Sci. Phila., No. 7, vi + 408 p., figs. 1–313.*

HERRE, ALBERT W. 1926. Four rare Philippine fishes. *Philippine Jour. Sci., 31: 217–225, fig. 1, pls. I–II.*

JORDAN, DAVID STARR AND BARTON WARREN EVERMANN. 1898. The fishes of North and Middle America ... *Bull. U. S. Nat. Mus., No. 47, Pt. III, p. i–xxiv + 2183a–3136.*

LONGLEY, WILLIAM H. AND SAMUEL F. HILDEBRAND. 1941. Systematic catalogue of the fishes of Tortugas, Florida. *Carnegie Inst. Washington Pub. No. 535 (Pap. Tortugas Lab., Vol. 34), xiii + 329 p., pls. 1–34.*

METZELAAR, J. 1919. Report on the fishes, collected by Dr. J. Boeke, in the Dutch West Indies, 1904–1905, with comparative notes on fishes of tropical West Africa. *Rapport Viss. Ind. Zee. Kolonie Curacao, 2(Pt. 2): 1–316, figs. 1–64.*

NICHOLS, J. T. 1930. The fishes of Porto Rico and the Virgin Islands. Pomacentridae to Ogcocephalidae. *N. Y. Acad. Sci., Sci. Serv. Porto Rico, 10(Pt. 3): 299–399, figs. 175–314.*

NORMAN, J. R. 1935. Coast fishes. Part I. The South Atlantic. *Discovery Repts., 12: 1–58, figs. 1–15.*

PARR, ALBERT EIDE. 1930. Teleostean shore and shallow-water fishes from the Bahamas and Turks Island. *Bull. Bingham Oceanogr. Coll., 3(Art. 4): 1–148, figs. 1–38.*

SMITH, J. L. B.
1950. The sea fishes of Southern Africa. *Central News Agency, Ltd., Cape Town, xvi + 550 p., figs. 1–1232, pls. 1–103.*
1955. New species and new records of fishes from Mocambique. Part I. *Memorias do Museu Dr. Alvaro de Castro, No. 3, p. 1–27, figs. 1–32, pls. I–III.*
1956. An extraordinary fish from South Africa. *Ann. Mag. Nat. Hist., Ser. 12, 9: 54–57, pl. I.*

SPRINGER, STEWART AND HARVEY R. BULLIS, JR. 1956. Collections by the *Oregon* in the Gulf of Mexico: List of crustaceans, mollusks, and fishes identified from collections made by the exploratory fishing vessel *Oregon* in the Gulf of Mexico and adjacent seas, 1950 through 1955. *U. S. Fish and Wildl. Serv., Spec. Sci. Rept.: Fish. No. 196, p. 1–134.*

WEBER, MAX AND L. F. DE BEAUFORT. 1936. The fishes of the Indo-Australian Archipelago. VII. Perciformes (continued). *E. J. Brill, Ltd., Leiden, xvi + 607 p., figs. 1–106.*

SOUTH ATLANTIC FISHERY INVESTIGATIONS, U. S. FISH AND WILDLIFE SERVICE, BRUNSWICK, GEORGIA.

ERRATUM: line 26, column 2, page 124, should read 25°13' N., 77°07' W.

PRODUCTION AND UTILIZATION OF SEED OYSTERS IN THE GULF AREA

Philip A. Butler

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The variety of environmental conditions along the extensive Gulf Coast imposes a great diversity of techniques in oyster culture, making it difficult for one person to have available current information on the entire industry. For this reason, I have called upon marine biologists in each of the states for assistance in assembling some of the data essential to our discussion. I should like to acknowledge their helpfulness and cooperation in providing information; the interpretation placed upon these data and any errors in statement are my own.[1]

In order to simplify organization of the information, I submitted a questionnaire to these gentlemen. This material can be covered most efficiently by itemizing some of the questions and replies. It is essential that we have a clear understanding of the term "seed oyster." While most biologists attach a definite meaning to the term, among oystermen, especially from different geographic areas, you will find that the concept of a "seed oyster" undergoes considerable change.

The first question, then, was "What does the term 'seed oyster' mean to oystermen in your state?" The replies were briefly as follows: no precise meaning, oysters to be replanted, any oyster under legal size, and any oyster not legally subject to harvest. Perhaps some of these definitions are broader than what your own local industry understands by the term. For the purposes of this discussion I am using the term "seed oyster" to include any oysters of less than legal size which would be transplanted primarily for the purpose of growing to a larger size. We are not concerned here with market-size oysters that frequently are replanted for conditioning, to await a more favorable market, or to cleanse them of pollution.

The next question asked was "Does your state provide for restricted or closed areas for the production of seed oysters?" We learn that in the approximately 3,500 miles of Gulf coast line there are about 350,000 acres of water bottom set aside for seed culture, all in the state of Louisiana. This does not imply that all, or even the majority, of this area is in production at any one time. We asked also if there are any public reefs or polluted areas where larger oysters are harvested primarily for transplanting to growing grounds. Two states answered in the affirmative; in the past biennium Florida had a special situation in which oysters

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[1] Robert M. Ingle, Assistant Director, Florida State Board of Conservation; Harold Loesch, Marine Biologist, Alabama Conservation Department; Gordon Gunter, Director, Gulf Coast Research Laboratory; Lyle St. Amant, Chief Biologist, Louisiana Wildlife Fisheries Commission; Robert Hofstetter, Marine Biologist, Texas Game and Fish Commission.

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from a polluted reef were transplanted to a new growing area; and in Alabama, there was some production from deep-water reefs of older mixed oysters which were replanted on tonging reefs or on private growing grounds.

The question must arise in your minds that if this is the extent of seed oyster culture in the Gulf, is there no demand for additional seed. In answer to this question, the reply from three of the Gulf states was they have no significant demand. In Alabama, a few private planters could utilize additional amounts of seed oysters, and in Louisiana there is some demand, but it is almost satisfied by the state seed oyster program. In none of the states is there any import or export of seed oysters for transplanting purposes and none of the biologists felt that the oyster industry in his state provides a potential market for out-of-state seed.

The question must also arise in your mind then, as to just what the Gulf oyster industry does rely upon for its source of oysters ---certainly not exclusively on the natural reef community? The answer is found in the replies to our question "Has your state planted any cultch?" I will not give any of the figures, but all of the states do plant shell; although in Texas it has recently been only on an experimental basis. It is significant that the size of the oyster harvest in the various states corresponds roughly to the extent of the shell planting program.

This brief survey of the situation points out fundamental differences in the oyster industries of the Gulf and the North Atlantic states. Although a shell planting program is undertaken in both areas, transplanted seed oysters are the mainstay of the business in the northern waters.

Oyster communities in the Gulf of Mexico are still on a more nearly self-perpetuating basis than those in the depleted areas along the Atlantic Coast. But this is perhaps merely an illusion and we are actually witnessing the slow and progressive deterioration of an overharvested resource which eventually will require drastic help if it is to remain productive. It is remarkable that after a hundred or more years of commercial harvesting, the Gulf oyster community can still be productive with only the moderate and erratic assistance of additional cultch.

It is reasonable to predict that in the future man is going to encroach more and more on the environments suitable for oyster culture. Depletion will increase and the present bountiful spatfall will be decimated if remedial measures are not undertaken. Then, the only way the industry will be able to survive will be by the use of transplanted seed oysters as in New England now.

This is not intended as a gloomy prediction, it seems to me to be an obvious conclusion to be derived from the history of the oyster

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A CONTINUOUS WATER SAMPLER FOR ESTIMATION OF DAILY CHANGES IN PLANKTON

PHILIP A. BUTLER AND ALFRED J. WILSON, JR.

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The growth rates of oysters held in experimental trays suspended above the bottom at two stations only 1000 feet apart on either side of our laboratory island have differed markedly for the past several years (Butler 1953). At the east station, the oysters grow faster, mortality is somewhat lower, and more young oysters attach to test cultch. Although we have not checked other marine animals as closely, this station appears to be equally favorable for clams and scallops as well as such sedentary forms as barnacles, mussels and sea-squirts.

During the past year when we have maintained continuous records, average monthly salinity levels have differed by less than 0.5 °/oo and temperatures have differed by less than 1.0° C at the two stations. In the absence of other data, quantitative or qualitative differences in food appear to be the most plausible explanation for this situation. Knowledge of the fundamental causes for such differing growth patterns under apparently similar conditions would be of great practical importance to the oyster industry, and for this reason, we have undertaken an investigation of the problems involved.

Since shellfish are filter feeders, the logical starting point in our investigation was to obtain estimates of plankton concentrations and fluctuations at the two stations over a period of time. An accurate method for the collection and estimation of plankton was essential. Enumeration of the plankton was not considered feasible because of the time involved, but there are several methods for estimating chlorophyll, which is an indirect measure of phytoplankton abundance. In the past, chlorophyll concentrations have been reported in terms of the arbitrary Harvey Unit, but with the advent of the quartz spectrophotometer, it is possible to measure accurately and quickly the different chlorophylls as well as other plant and animal pigments. The remaining requirement for this investigation was, then, a suitable method for collecting valid plankton samples.

The discontinuous pattern of the plankton biomass in the sea from day to day and even from hour to hour creates real difficulties in sampling methods. Spot sampling may produce an entirely erroneous picture. Samples collected hourly from the waters near our laboratory may vary tenfold in volume of plankton on the same day. Consequently, we required some method for collecting continuously a relatively small amount of water which could be analyzed periodically for its plankton content.

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Capillary bleeders are described in the literature to fulfill this need, but we found them impractical. They clog easily, are tedious to calibrate, and their rate of flow varies with changes in water depth. When this type of collector is submerged, an unknown amount of water surges into the sample bottle until a pressure equilibrium is reached. It is almost impossible to evaluate the error introduced in this way.

After much trial and error we have developed the arrangement of equipment shown in Figure 2, which overcomes the disadvantages of a capillary bleeder collector and offers some distinctive advantages. We are using this apparatus routinely in our investigation of plant pigments at the two stations.

As shown in the diagram, the essential feature of the apparatus is the connection of both vacuum and pressurelines to the six-liter collecting flask. The degree of vacuum is controlled by the stopcock. Pressure can be applied to the system by means of the three-way valve. Water is admitted to the sample bottle through the inlet tube, which has a seven to eight millimeter bore.

In use, pressure is applied to the system, and the sliding rack holding the collecting flask is lowered to the desired level under water. The rack, weighted to counterbalance the buoyancy of the flask, slides down a galvanized pipe set firmly into the bottom.

Pressure within the collecting flask prevents any initial surge of water through the inlet tube. When the rack is in position, the three-way valve is turned to close the pressure line. Excess pressure is relieved by the escape of air out of the inlet tube, and equilibrium with the outside water is established almost immediately. The three-way valve is turned again to apply suction to the system, and water flows into the flask at the pre-regulated rate. The relatively large bore and slight current make clogging of the inlet tube unlikely. At the same time, they may hinder the collection of long chains of phytoplankton and elongate or highly motile macroscopic zooplankton. At the end of the collecting period, the rack is vigorously shaken to mix the sample thoroughly. As the rack is raised and pressure decreases on the system, there is a surge of water out of the collecting flask. Since this is an aliquot of the sample, its loss is of no importance.

The rate of collection is dependent on the adjustment of the stopcock: it may be varied so as to fill the collecting flask within any desired interval from a few minutes to 96 hours. We adjust the stopcock by trial and error so that approximately 20 drops of water per minute flow through the inlet tube. At the end of 24 hours the flask is approximately 80 per cent full and the sample is representative of the entire mass of water that has flowed past the station during that period of time. Since the rate of flow in any one collecting flask stay uniform, differences in the flow rate and total volume collected at two different stations are of no significance providing, further, that the collections are simultaneous and each sample is less than the capacity of the flask.

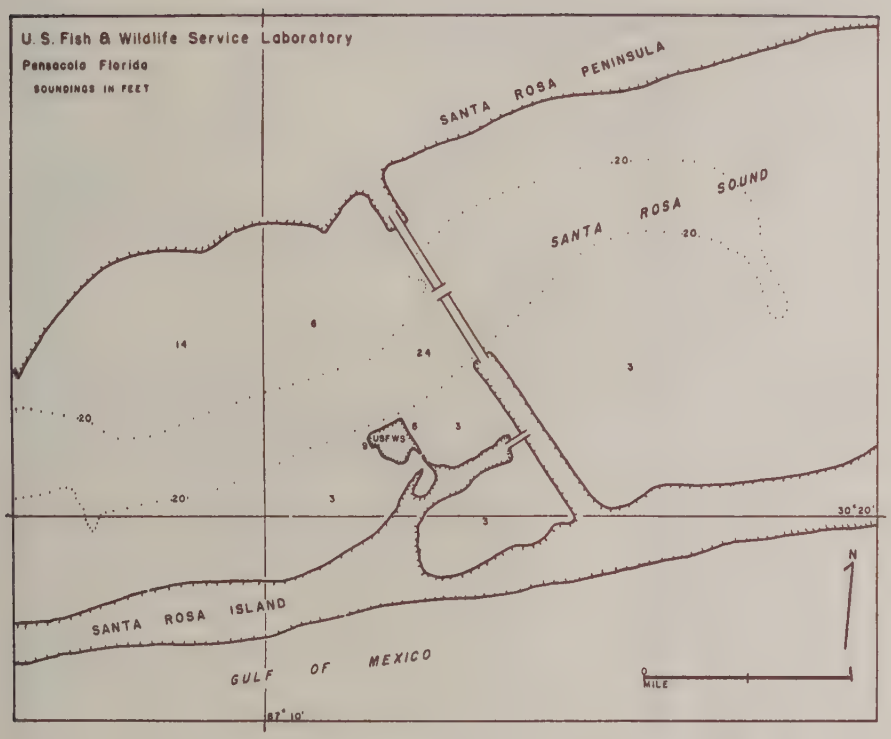

Fig. 1. Chart of the laboratory island, U. S. Fish and Wildlife Service, showing the location of the two sampling stations at the nine and six foot soundings on either side of the island.

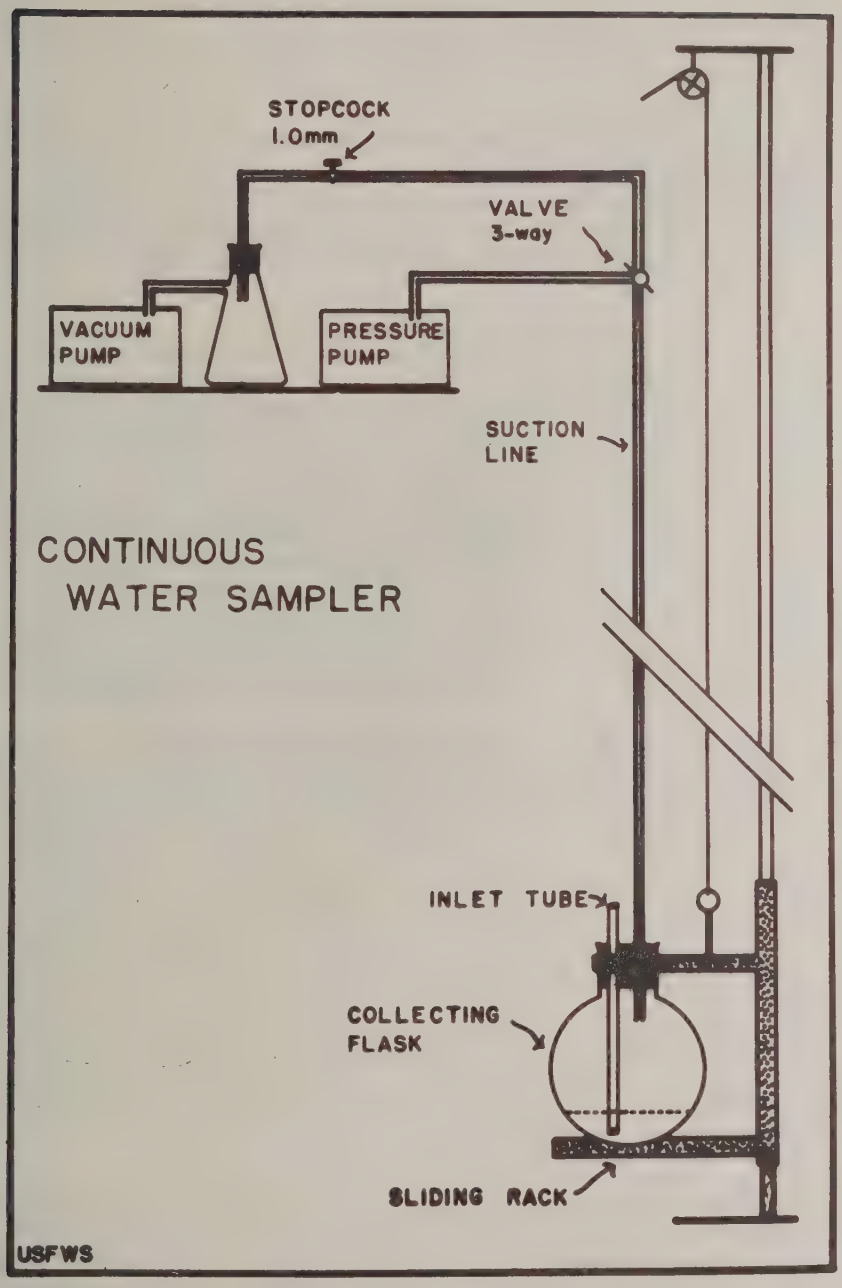

Fig. 2. Diagram of equipment used in collecting water samples.

With this arrangement of the collecting equipment, there is no necessity for the tedious calibration ordinarily required when using duplicate collectors.

The critical point in the entire system is the original adjustment of the stopcock on the vacuum line. This is most easily accomplished by transferring the suction line temporarily to a trial collecting flask fitted with an inlet tube. With this flask submerged in a large battery jar, the stopcock can be adjusted by observing the rate of flow into the trial collecting flask.

Our analytical procedure for estimating concentrations of plant pigments depends on a combination of techniques fully described in the literature. Briefly, plankton is removed from the water samples by suction filtration using Millipore AA filters, as described by Goetz and Tsuneishi (1951). Such filters retain particles having a diameter of 0.8 micron or greater as well as many smaller ones. Depending on the concentration of plankton, samples can be filtered at the approximate rate of one liter per hour. The cellulose ester filters are dried in vacuo, dissolved in acetone and absorbencies of the samples are read with a Beckman DU spectrophotometer. Concentrations of chlorophylls a, b and c as well as astacin and non-astacin carotenoids can then be calculated using formulae published by Richards and Thompson (1952).

At present, we collect one sample per station per day for four consecutive days each week and analyze them individually for plankton pigment concentrations. We consider these four-liter samples to be valid aliquots of the millions of gallons of water flowing past each station daily. The effectiveness of this apparatus for collecting representative samples may be judged by comparing the average monthly salinity of its samples with data obtained from another water sampler used routinely at this laboratory (Collier et al. 1953). This second device collects a small sample of water at hourly intervals from the continuously flowing salt water system of the laboratory. Although salinity levels may vary from day to day during the month by as much as 15 parts per thousand, average monthly data obtained using these two collecting methods are in frequent agreement and, during the past year, havenot differed by as much as one part per thousand.

We have been conducting this program of plankton pigment analyses for several months now and find that initial results are consistent and show characteristic trends at the two stations. Chlorophyll a appears to be the most significant component of the pigment complex and ranges in concentration from approximately 1.0 to 12.0 mg/M^3. Both chlorophyll a and c fluctuate greatly from day to day, but changes in their average concentrations seem to be directly related to changes in average water temperatures.

Summary

The water collecting device described here has special features which may be of value to other investigators. Its application is limited to fixed installations such as docks. Its chief advantage lies in its capacity to collect a relatively small aliquot from a large mass of water during a period of one or more days. Such samples have obvious value for estimating average concentrations of both particulate matter in the plankton and dissolved ions including nutrient salts and trace elements.

Literature Cited

Butler, P. A. 1953. Importance of local environment in oyster growth. Proc. Gulf & Carib. Fish. Inst., 5th Ann. Session: 99-106.

Collier, A., S. M. Ray, A. W. Magnitzky, and J. O. Bell. 1953. Effect of dissolved organic substances on oysters. U. S. Fish and Wildlife Service, Fish. Bull. 54(84): 185.

Goetz, A., and N. Tsuneishi. 1951. Application of molecular filters to the bacteriological analysis of water. Jour. Amer. Water Works Assoc. 43: 943-969.

Richards, F. A., and T. G. Thompson. 1952. The estimation and characterization of plankton populations by pigment analyses. II. A spectrophotometric method for the estimation of plankton pigments. Jour. Mar. Res. 11(2): 156-172.

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The problem of the Atlantic Ridley Turtle (Lepidochelys kempi) in 1958*

by

Archie Carr** and David K. Caldwell***

(Received for publication October 15, 1958)

The general nature of the enigma posed by the Atlantic ridley (*Lepidochelys kempi*) has been outlined by CARR (2, 3, 4, 5, 6), and by CARR and CALDWELL (7). Although gaps in our understanding of the zoogeography and reproductive life of the ridley remain, slow progress toward a solution is being made. Recent observations along the Mexican shore of the Gulf of Mexico, showing that ridleys nest at least occasionally in Veracruz, together with other bits of relevant information, are discussed below.

Except for GARMAN'S (11) type specimen, only two mature ridleys have hitherto been known to zoologists. One of these was raised in captivity in the tanks of Marine Studios, Marineland, Florida, where it attained a weight of about 100 pounds, mated with a captive loggerhead, *Caretta caretta caretta,* and later laid eggs which were dropped in the water and thus could not be tested for viability (see CARR (6)). The other was a 93-pound individual with nearly mature eggs in the oviduct, taken by fishermen at Crystal River on the Gulf coast of Florida (CARR and CALDWELL (7)).

Recently, photographs of other ridleys of a size above the maximum for the populations known along the Gulf and Atlantic coasts of the United States have come to our attention. Strong sexual divergence is evident in these pictures, and since the sexual differences have not been illustrated elsewhere,

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Contribution No. 32
U. S. Fish & Wildlife Service
Bureau of Commercial Fisheries
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Brunswick, Georgia

we show the photographs as figures 1-3. The individual in figure 1 is clearly a female, as indicated by the short tail. It was taken in a small shrimp trawl, by the United States Fish and Wildlife Service's original M/V PELICAN, at Station 97-2 in 14 fathoms on January 14, 1939. The position of Station 97-2 was latitude 28° 36' N., longitude 90° 11' W., about 65 miles south of Morgan City, Louisiana, in the northern Gulf of Mexico. Although not measured, the turtle appears to have had a carapace length of about 29 inches. According to the conversion formula given by CARR and CALDWELL (7), this length would put it in the 90- to 100-pound class, making it one of the two of three largest ridleys known. The turtles in figures 2 and 3 were captured somewhere in Florida when small and were taken to the old New York Aquarium. When the aquarium was later torn down they were sent to the Government Aquarium at Flatts, Bermuda. The photographs were sent to us by Mr. Louis S. Mowbray, Curator at Bermuda, when the turtles were transferred from Bermuda to the new aquarium in New York, where they are still living. Measurements are lacking for these specimens also, but the pair is of interest because of the marked disparity in tail length shown. This not only indicates that they are probably mature individuals, but is another morsel of proof of reproductive orthodoxy in the Atlantic ridley. That is to say, they make it seem more likely that the ridley has two sexes (see CARR, 2, 4, 5; CARR and CALDWELL, 7).

Although we have never before seen an Atlantic ridley determinable as a sexually mature male, the older fishermen on the West Coast of Florida say that big, long-tailed individuals were often taken in former days, when the turtle fishery at Crystal River and Cedar Key was carried on much farther off shore than at present. Several of these old-timers have told us that ridleys in the offshore fishery ran larger than those taken in the shallow water about the river mouths where most of the turtling is now done. The fact that the big ridley in figure 1 was also caught offshore, some 35 miles from land, suggests either a more offshore habitat for the adult ridley than has hitherto been supposed or a life cycle that involves deep-water migration. Contributing evidence (CARR, 6) makes the latter conclusion seem the more likely.

While these bits of information were accumulating, some very small juveniles of the species were found in the southwestern Gulf of Mexico near Nautla and Alvarado, Mexico, under circumstances suggesting that they had hatched locally (FUGLER and WEBB, 10). In an effort to substantiate the occurrence of, and determine the extent of nesting in the area, Carr spent five weeks of the winter of 1957 on the coast of Veracruz, visiting points from Tampico southward to Coatzacoalcos, in the extreme southern end of the Gulf (figure 4). Though this period did not correspond with the nesting season, said by local people to be May and June, conversations with large numbers of fishermen and examination of turtle shells and skulls remaining from the preceding season yielded data, which though meager, seem trustworthy.

In a short extent of the Veracruz coast, from Tuxpan to a few miles south of Alvarado, people consistently claimed that a fifth kind of sea turtle occurred (besides the Atlantic green turtle, *Chelonia mydas mydas* (Linnaeus);

the Atlantic hawksbill, *Eretmochelys imbricata imbricata* (Linnaeus); the Atlantic loggerhead, *Caretta caretta caretta* (Linnaeus); and the Atlantic leatherback, *Dermochelys coriacea coriacea* (Linnaeus)). Here everybody who seemed to know anything about turtles recognized the fifth kind, called it either *lora* or *cotorra* (both of which mean parrot, and are presumably prompted by the psittacine beak of the ridley) and described it in terms unmistakably indicative of *Lepidochelys*. During this investigation some 100 fishermen were interviewed in 23 localities in Veracruz, and agreement that the *lora* or *cotorra* exists and nests there was practically unanimous. That it was actually the ridley referred to received more material proof when Carr came suddenly upon a seaside *cantina* a few miles north of Alvarado with three ridley shells nailed to its wall (figure 5). The shells had been painted red, and were visible from far down the highway, as if marking for the traveller the long-sought nesting ground of the ridley. A group of fishermen there stated positively that the shells belonged to the kind of turtle they called *lora,* and that the *lora* came regularly ashore to lay.

At every locality surveyed, the people said that although the ridley nests there it never comes out in numbers but is seen only once or twice during a season. Nowhere did there seem to be any knowledge of rookeries, such as the assemblages of loggerheads on the lower East Coast of Florida or at Jekyll Island, Georgia, or like the green turtle rookery at Tortuguero, Costa Rica.

To investigate this point more fully, Carr returned to Veracruz in May, 1958, timing his visit to coincide with the alleged height of the nesting season of the *cotorra.* Between May 30 and June 8 the following localities were visited: Tampico, Tuxpan, Veracruz, Boca del Rio and beaches to the south of that town, Anton Lizardo, Isla de Sacrificios, and Alvarado. Although no valid measurements for quantitative appraisal of the situation could be devised, the beaches were searched carefully for tracks, fish markets were visited, and a standardized pattern of questioning of local fishermen was carried out. It was concluded that while ridleys certainly nest in Veracruz, no rookery occurs in the extent of territory between Alvarado and Nautla. Nesting by all species of sea turtles there appears relatively meager. At Tampico, people questioned had been frightened by a recent eruption of law enforcement by the local fisheries office, and the resulting skittishness before questioning made it impossible to learn anything of value. The coast north of Tampico, especially, requires further attention.

At Coatzacoalcos in the extreme southern end of the Gulf, magnificent sand beaches extend eastward and westward of the mouth of the Coatzacoalcos River. On sample two-mile stretches searched for tracks and for old nesting sign, there was no evidence of any nesting activity whatsoever. Interviews with people along this shore, and back in town at the fish wharves, revealed the curious anomaly of good-looking sea beach on which sea turtles of all sorts are completely unknown. In the few cases in which a person talked to claimed to have found a turtle on the shore this turned out to have been a freshwater species, evidently carried out to sea by the current of the nearby river and thrown

Fig. 1: Large live female *Lepidochelys kempi* from off Morgan City, Louisiana. (Photograph through the courtesy of William W. Anderson).

Fig. 2: Live female *Lepidochelys kempi* raised in captivity from specimen taken while young. Note short tail. (Photograph through the courtesy of Louis S. Mowbray).

Fig. 3: Live male *Lepidochelys kempi* raised in captivity from specimen taken while young. Note long tail. (Photograph through the courtesy of Louis S Mowbray).

1

2

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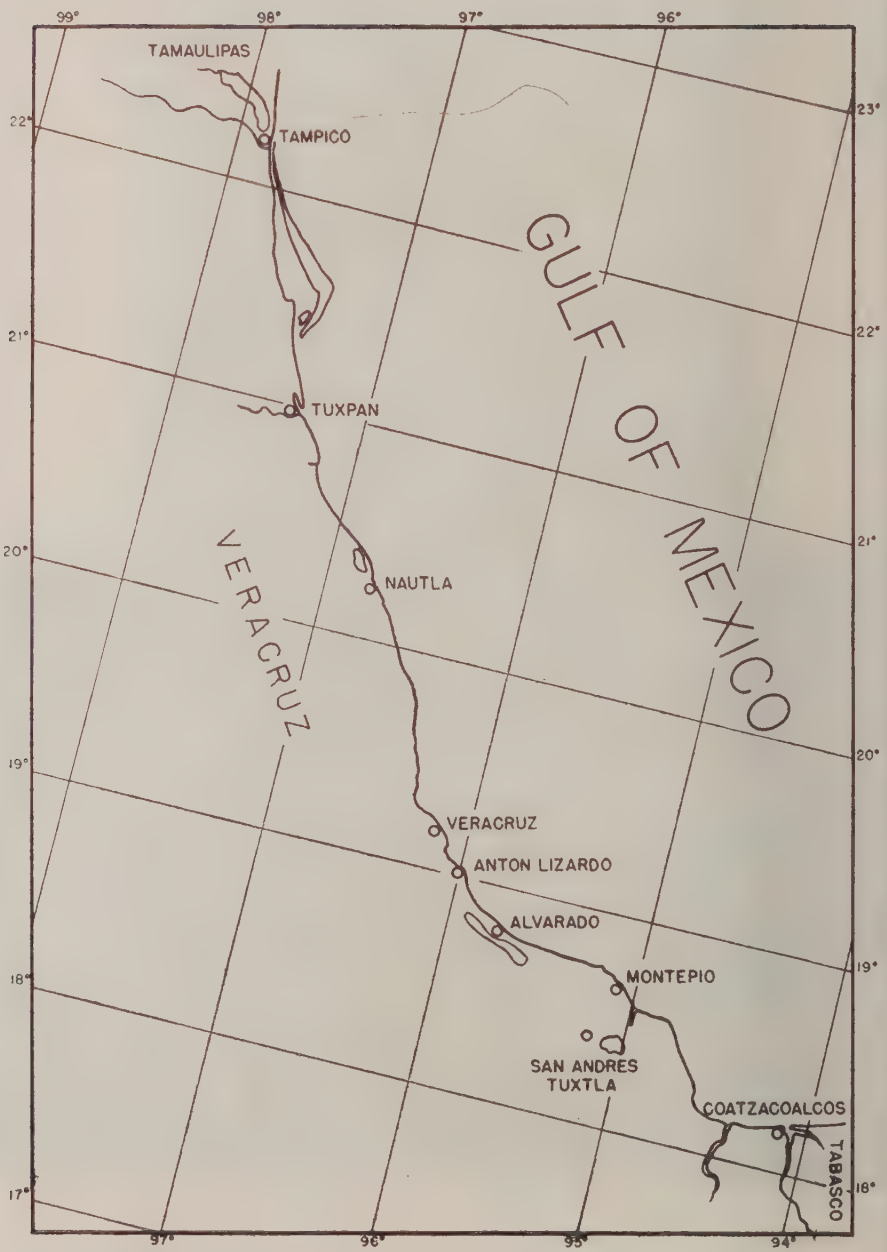


Fig. 4: Map showing the localities in the state of Veracruz, Mexico, referred to in the text.

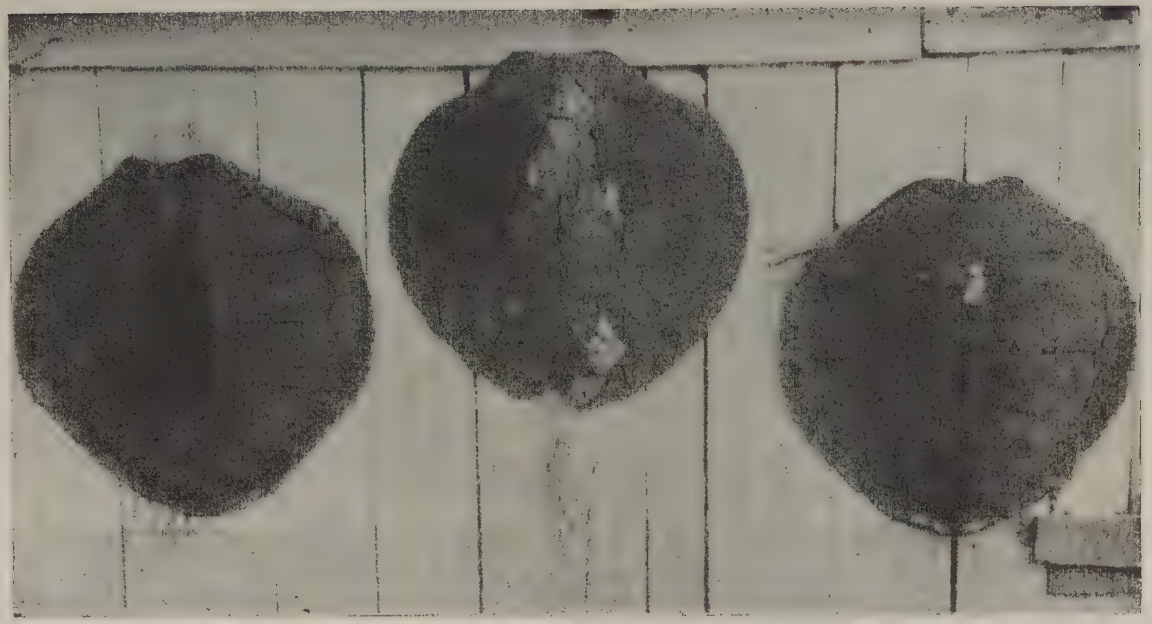


Fig. 5: Shells of three *Lepidochelys kempi* on wall of *cantina* near Alvarado, Veracruz, Mexico. The turtles allegedly had been taken when nesting and the shells had been painted and hung on the shop through some whimsey of the owner. This was within 25 miles of a locality where two other nesting females were later found (see text).

onto the beach by the surf. Here at Coatzacoalcos it was generally agreed that sea turtles nest in abundance at the foot of a mountain to the northward, at a place called Montepio, abreast of the Tuxtlas. Later inquiries at Veracruz, Alvarado, and San Andres Tuxtla produced the same information. Since it was not possible to approach Montepio by road during the rainy season, and since time was not available for a trip in on mule-back, substantiation of the somewhat widespread allegations was not secured.

DERANIYAGALA (8) made the surprising statement that the ridley is now known to nest on beaches around Miami, Florida, but adduced no information to support the remark, which was published at the time the discovery of young in Veracruz was announced. If a South Florida nesting ground was deduced on the basis of the finding of baby turtles in southern Mexico we find the idea unconvincing, since the present knowledge of current systems in the Gulf of Mexico (SVERDRUP, JOHNSON, and FLEMING, 15; LEIPPER, 12) stands in the way of an assumption that little, weak, and probably only days-old turtles could have swum or drifted from Florida to the places where they were found.

Judging from the pattern emerging from current studies of reproduction in other sea turtles, it seems likely that, somewhere, mass nesting by ridleys occurs. The coast of Quintana Roo was named by CARR (6) as an alleged breeding ground of the *"cotorra,"* now believed to be almost without doubt the ridley; but although heavy nesting does occur there it is mostly by other species and occurrence of the ridley is said to be limited to the sporadic emergence of an individual in the rookeries of the others, as loggerheads come out on the Tortuguero green turtle beach. Despite the apparent absence of *L. kempi* in the Caribbean, there is some unexplored territory there, and it still seems possible that a part of the American Atlantic ridley population could be derived from West Africa—either from somewhere within the range of the form that lives about and below the bulge, and in the Gulf of Guinea and which has predominantly six lateral laminae, or from the long extent of shore from Port Etienne to Morocco, where nothing is known of the turtle fauna (see CARR, 6). There remains also a need for a careful search of the South American coast from Belem northward to the mouth of the Orinoco River, especially in Dutch Guiana.

The South American coast south of Belem appears to offer no solution and indeed only adds anomaly to the situation, since it seems to represent a complete interruption of the range of the genus. CARR (6) commented on his failure to find ridleys anywhere between Belem and Recife. LUEDERWALDT (13) did not include the ridley among the sea turtles known from Brazil, and it was lacking in FREIBERG'S (9) list for Argentina. During August, 1958, Carr found the ridley to be also completely unknown to fishermen and fisheries officers in southern Brazil and in Argentina. This surprising development was corroborated by results of examination of the sea turtle collections in the Museu Nacional at Rio de Janeiro, at the Museo Nacional in Buenos Aires, and the La Plata Museum at La Plata (Argentina). In these institutions a total of 42 specimens, representing all four other genera of sea turtles, was examined.

There was no specimen of *Lepidochelys* among them. It seems, thus, that southern South America not only offers little promise as a place of origin of five-scaled ridleys, but constitutes another of the curious gaps, like the Caribbean Sea and the western shore of the Indian Ocean, in the world distribution of this odd genus of reptiles.

While various kinds of circumstantial evidence support the inference from Fugler's and Webb's finding of recently-emerged young, that *Lepidochelys* nests in Veracruz, the only proof based on direct observation was the finding by Carr of two female ridleys that had nested on the beach at Anton Lizardo on June 8, 1958. The two turtles had emerged within a quarter of a mile of each other and had been found and butchered by Mexicans, who in spite of protective laws patrol the beach religiously, and probably rarely miss a turtle that comes out. The eggs had been taken away, and no amount of cajoling would persuade anyone to produce them, since at this place, too, temporary uneasiness over threats of law enforcement was in the air.

The shells of these two individuals were low and smoothly domed, with no mid-dorsal depression such as is often seen in breeding female *L. olivacea* (Eschscholtz). The greatest straight-line lengths of the two carapaces were, respectively, 652 mm. (about 25 ¾ inches) and 640 mm. (about 25 ¼ inches) and as is frequently the case in juvenile specimens (CARR and CALDWELL, 7), the shells were nearly circular as seen from above, the former being two mm. longer than wide and the latter eight mm. longer than wide. Both had five laterals on either side, and four enlarged inframarginals (some of which on each side were provided with a pore).

While these findings are of interest as substantiation of Fugler's and Webb's evidence that the Gulf coast of Mexico is a region where the ridley nests, they do not seem to justify an assumption that Veracruz, or at least that the parts of it visited by Carr, can be the sole site of origin of the abundant five-scaled ridleys of the western Atlantic. Since all evidence at hand indicates that the populations of immature ridleys in Florida and along the Atlantic coasts of the United States are large ones (CARR and CALDWELL, 7), the Mexican beaches so far visited seem insufficiently productive to account for the yearly recruitment in Florida waters.

However, Dr. Henry Hildebrand writes us that while carrying out ichthyological field studies at Laguna Madre in Tamaulipas he heard stories of an Arab trader who several times each season takes forty or fifty burros to the vicinity of Punta Juárez, about 40 miles north of Tampico, and brings them back loaded with turtle eggs. Dr. Hildebrand could not find out what species of turtle was supposedly involved. He thought that the stories were greatly exaggerated but perhaps had some rudiments of authenticity. Even a tenth the alleged number of burros could carry a lot of turtle eggs. If there is any such nesting ground there, and if ridleys use it heavily, it and the rookery rumored to exist at Montepio might conceivably account for the Gulf populations of ridleys and make it unnecessary to postulate their derivation from more distant sources (cf. CARR, 6).

The four specimens agree in the following characters: one precentral; Nautla and Alvarado were not figured or adequately described. FUGLER and WEBB (10) gave brief counts and measurements and DERANIYAGALA (8) provided some color notes. Through the kindness of Mr. John M. Legler of the Museum of Natural History of the University of Kansas the four specimens have been made available to us for study and we offer the following additional information on them. Terminology used for the parts of the epidermal shell is that of CARR (2).

The four small specimens reported by FUGLER and WEBB (10) from one pair of postcentrals; one pair of pregulars; one pair of humerals; one pair of pectorals; one pair of abdominals; one pair of femorals; one pair of anals; four pairs of inframarginals (some on each side with discernible pores); three pairs of postocular scales.

In that the specimens differ somewhat in other characters, each is hereafter considered separately. All linear measurements were made with vernier calipers to the nearest tenth of a millimeter. The lengths are measured in a straight line, *not* following the curve of the shell. Weights are to the nearest twentieth of a gram, taken with a double-beam balance with the turtles blotted dry. Color notes (taken in late 1957) are from wet specimens. When dry, the animals lighten to a uniform light grey.

UKMNH 39558 (figure 6, lower right, and figure 7) has the following data on the label: "Lepidochelys olivacea kempi juv. 549 R. G. Webb 4 Mi. N. Nautla, Veracruz, Mexico—Purchased From Boy Wo Collected Specimen Along Beach 25 July 1955."

The specimen has five pairs of laterals ("costals" of FUGLER and WEBB); thirteen marginals on the left side and twelve on the right; and five centrals. In the ventral aspect, the specimen has a normal gular on the viewer's left, but the one to the right has its lower left corner split off to make an accessory scale. There is another small accessory scale between the gulars. The left pregular is enlarged.

The color is a dark grey, except for some almost white markings around the anus. Other light places, not as light as those around the anus, are: the outer edges of the marginals; the trailing edges of all the flippers; the points of the four plastral ridges (especially the central two); the nasals (with the nostrils lighter still); the edges, particularly the posterior edges, of the plastral plates (contrast here not strong—only really obvious under low-power magnification); the posterior corner of the maxillary scale; and the midventral tip of the beak.

The edges of the marginals show slight growth, the dorsal plates none.

Measurements: greatest length of carapace, 43.5 mm.; greatest width of carapace, 35.0 mm.; greatest depth of body, 22.3 mm.; greatest width of head, 15.0 mm.; weight, 21.25 grams.

UKMNH 39557 (figure 6, upper left, and figure 8) has the following data on the label: "Lepidochelys olivacea kempi Juv. 548 R. G. Webb Purchased In Alvarado, Veracruz, Mexico 22 July 1955."

This specimen has five pairs of laterals, thirteen left marginals (as seen in dorsal aspect) and twelve on the right, five centrals, and one pair of gulars.

The coloration is the same as that of UKMNH 39558.

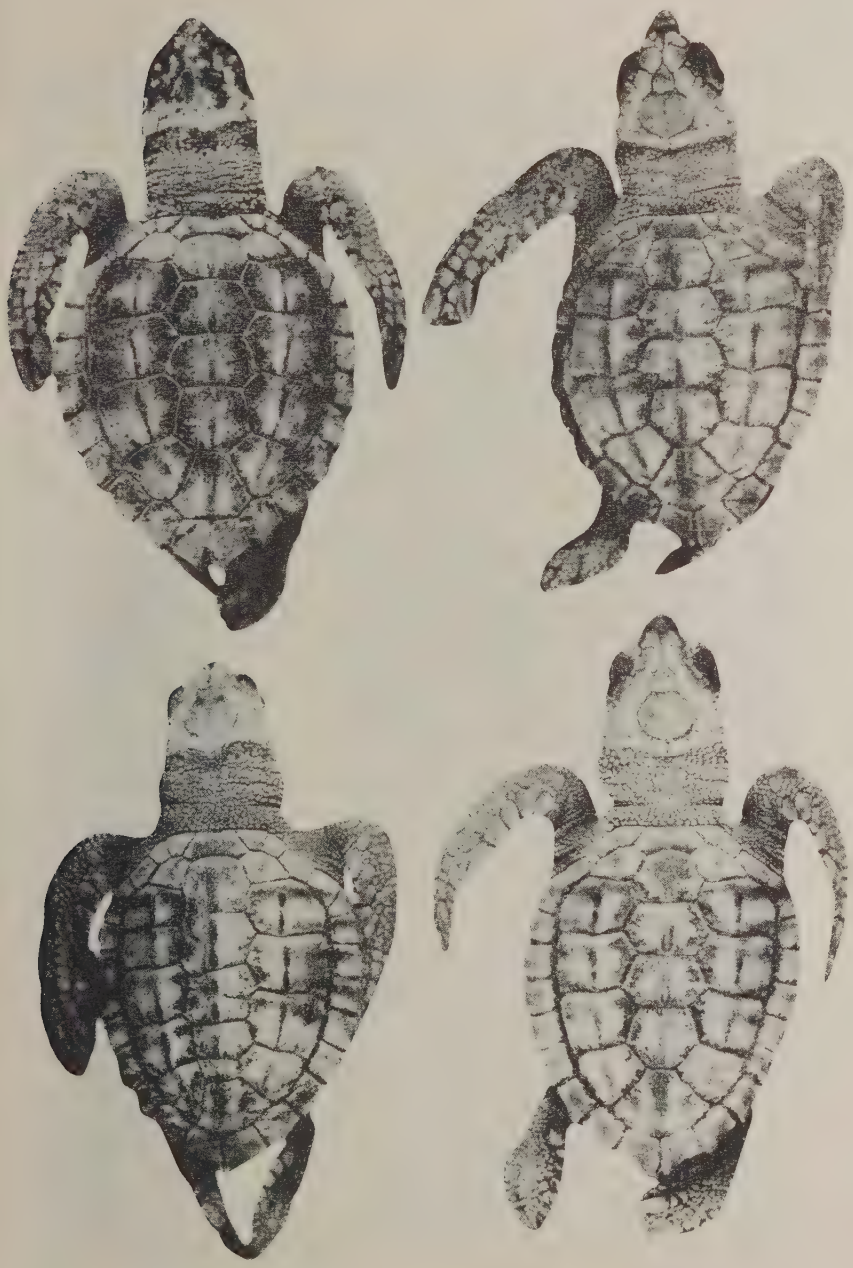
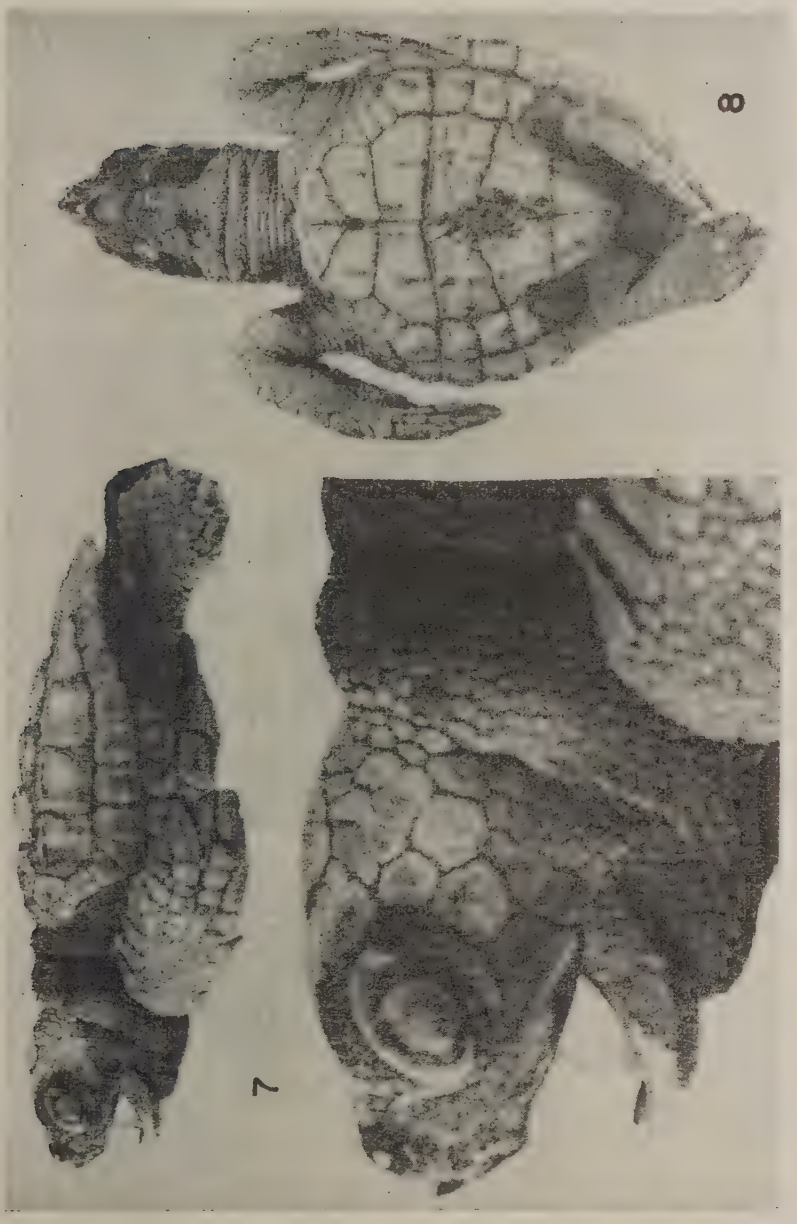


Fig. 6: Dorsal aspects of very young *Lepidochelys kempi* from the state of Veracruz, Mexico. See text for details. Upper left, UKMNH 39557; upper right, UKMNH 39555; lower left, UKMNH 39556; lower right, UKMNH 39558.

Fig. 7: Left lateral profile of very young *Lepidochelys kempi*, UKMNH 39558. Note strongly ridged back in upper view, and egg tooth in the enlargement of the same turtle in the lower view.

Fig. 8: Ventral aspect of very young *Lepidochelys kempi*, UKMNH 39557. Note umbilical scar.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Rio de Janeiro; Pablo Gaggero, Facultad de Ciencias, and Altair Emilio Rizzo, Preparator, Museo de La Plata, La Plata, Argentina; Jorge Crespo and Jorge A. Cranwell, Museo Nacional de Ciencias Naturales, Buenos Aires; Mr. and Mrs. Henri Casanova, Mocambo, Veracruz; William W. Anderson, United States Fish and Wildlife Service. For constructive criticisms of the completed manuscript we thank Mr. Anderson, Hugh M. Fields, and Jack W. Gehringer, all of the United States Fish and Wildlife Service at Brunswick, Georgia.

RESUMEN

El autor aporta nuevos datos al problema de la tortuga marina *Lepidochelys kempi*. Se publican fotografías ilustrativas del marcado dimorfismo sexual de esta especie (figs. 1 a 3), y se cita información de haberse visto machos adultos en la costa occidental de Florida. La evidencia parece indicar que esta especie habita más afuera en el mar que las otras especies, o tal vez, más probablemente, que su ciclo de vida implica migración a mar abierto. Algunos ejemplares juveniles de *Lepidochelys* fueron capturados en el Golfo de México; el autor visitó en diciembre y enero de 1957 la costa sudoeste de Veracruz desde Tampico a Coatzacoalcos (fig. 4), para investigar la posibilidad de que esta tortuga ponga sus nidadas en dicha región. La época no correspondía con la de reproducción de las tortugas, pero sí se obtuvieron algunos datos interesantes. Los habitantes de la costa desde Tuxpan hasta el sur de Alvarado mencionan como una de las cinco clases de tortuga marina que conocen, a la *lora* o *cotorra* de la que la descripción parece coincidir con los caracteres de *Lepidochelys*.

Unos 100 pescadores de 23 localidades confirmaron que esta *lora* o *cotorra* existe y anida en la costa de Veracruz. Cerca de Alvarado se encontraron en la pared de una cantina tres conchas de *Lepidochelys* que los pescadores vecinos aseguraron eran de tortuga *lora*. No hubo ninguna indicación de que la tortuga *lora* llegue a la playa en bandadas, sino más bien de que sus números son siempre pequeños.

En mayo y junio de 1958 el autor hizo otra visita a la costa de Veracruz. De sus observaciones se corrobora que *Lepidochelys* anida en esa costa, pero no se pudo localizar ningún criadero de importancia como existe para las otras especies marinas. Cerca de Coatzacoalcos se vio una playa arenosa perfectamente adecuada para la cría de tortugas, en la que éstas son completamente desconocidas.

Se critica la opinión de DERANIYAGALA (8) de que ahora se sepa que la *Lepidochelys* anide en las cercanías de Miami, Florida.

El autor también probó en 1958 la ausencia de *Lepidochelys* de la costa brasileña, así como de Argentina, como también de las colecciones del Museo Nacional de Río de Janeiro y de los museos Nacional (de Buenos Aires) y de La Plata. La costa de Sud América constituye, pues, otro de los hiatos problemáticos de la distribución de *Lepidochelys*.

En junio de 1958 el autor identificó dos ejemplares hembra de *Lepidochelys* atrapados en la costa de Veracruz después de desovar.

Si bien queda comprobado que esta especie anida en la costa mexicana del Golfo de México, los números en que lo hace no son suficientes para explicar el número de ejemplares que se encuentran en la costa de Florida. Quedan algunas localidades mexicanas por investigar, que pueden dar resultados importantes.

El autor redescribe cuatro ejemplares de *Lepidochelys* de Nautla y Alvarado, mencionados por FUGLER y WEBB (10), (fig. 6).

Las observaciones de este año indican el tamaño mínimo de la hembra adulta de *Lepidochelys,* y también que *L. kempi* es probablemente la menor de las especies de tortugas marinas. Sabemos ahora también que anida en junio o julio, y conocemos algunas localidades en que anida.

Parece posible, pues, que *Lepidochelys kempi* sea endémica en el Golfo de México, donde tal vez las localidades como Monte Pío y Punta Juárez sean centros de producción.

LITERATURE CITED

1. BLEAKNEY, S.
1955. Four records of the Atlantic ridley turtle, *Lepidochelys kempi,* from Nova Scotian waters. *Copeia,* 1955 (2):137.

2. CARR, A.
1952. *Handbook of turtles.* The turtles of the United States, Canada, and Baja California. Ithaca, New York: Comstock Publishing Associates, a division of Cornell University Press, XV + 542 pp., 37 figs., 82 pls.

3. CARR, A.
1954. The zoogeography and migrations of sea turtles. *Year Book of the American Philosophical Society,* 1954, pp. 138-140.

4. CARR, A.
1955. The riddle of the Ridley. *Animal Kingdom,* 58, (5):146-156 illus.

5. CARR, A.
1956. *The windward road.* New York: Alfred A. Knopf, XVI + 258 + VIII pp., illus.

6. CARR, A.
1957. Notes on the zoogeography of the Atlantic sea turtles of the genus *Lepidochelys. Rev. Biol. Trop.* 5 (1):45-61.

7. CARR, A. and D. K. CALDWELL
1956. The ecology and migrations of sea turtles, I. Results of field work in Florida, 1955. *American Museum Novitates,* N° 1793: 1-23, 4 figs.

8. DERANIYAGALA, P. E. P.
1957. The breeding grounds of the Luth and the Ridley. *Herpetologica,* 13, (2):110.

9. FREIBERG, M. A.
1938. Catálogo sistemático y descriptivo de las tortugas argentinas. *Memorias del Museo de Entre Ríos*, 9:1-23, 8 pls.

10. FUGLER, C. M., and R. G. WEBB
1957. Some noteworthy reptiles and amphibians from the states of Oaxaca and Veracruz. *Herpetologica*, 13 (2):103-108.

11. GARMAN, S.
1880. On certain species of Chelonioidae. *Bulletin Museum Comparative Zoology, Harvard*, 8:4-8.

12. LEIPPER, D. F.
1954. Physical oceanography of the Gulf of Mexico. In Galtsoff, Paul S., Gulf of Mexico. Its origin, waters, and marine life. *United States Fish and Wildlife Service, Fishery Bulletin*, 89:119-137, figs. 34-43.

13. LUEDERWALDT, H.
1926. Os chelonios brasileiros. *Revista Museu Paulista*, 14:1-66, 4 figs., 11 pls.

14. MOWBRAY, L. S., and D K. CALDWELL
1958. First record of the ridley turtle from Bermuda, with notes on other sea turtles and the turtle fishery in the islands. *Copeia*, 1958 (2):147-148.

15. SVERDRUP, H. U., M. W. JOHNSON, and R. H. FLEMING
1942. *The oceans*. New York: Prentice-Hall, X + 1087 pp., 265 figs., 121 + V tables, 7 charts.

p. 246 l. 9 read "..two or three.."
p. 254 l. 23 read "..boy who.."
p. 258 l. 14 read "The centrals.."
p. 259 l. 24 read "(Garman, 11)"

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FOSSIL FISH TEETH OF THE FAMILY SPARIDAE FROM FLORIDA

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From a Pliocene locality in Florida I recently reported and figured (Caldwell, 1957: 151) two fossil fish incisor teeth referred to the sparid genus *Lagodon* Holbrook, and tentatively ascribed to the species *Lagodon rhomboides* (Linnaeus). This deposit, near the village of Haile, Alachua County, Pit VI, A, located in SW ¼, Sect. 24, R. 17 E., T. 9 S., is in the Alachua formation and is considered to be Middle Pliocene (Hemphillian) in age (Auffenberg, 1957: 14). The locality is thought to be of freshwater origin (Goin and Auffenberg, 1955: 500, 503), and more especially, a sinkhole or fluviatile deposit (Auffenberg, 1955: 135). Because of the presence of *Lagodon*—a marine species known to ascend into fresh water—I proposed (Caldwell, 1957: 152) that the deposit might represent an ancient spring or stream near the seacoast. I also suggested, after consultation with Dr. Auffenberg, that perhaps the sparid teeth were residua from a slightly older marine deposit reworked by the fresh water or that they were deposited during a short-term marine inundation soon after the original freshwater deposit was laid down. The teeth do not indicate long-term waterwear and their condition is quite similar to that of freshwater fossils from the deposit, though it cannot certainly be said that they are of exactly the same age or from identical ecological conditions.

Careful working of this same deposit by Dr. Auffenberg has now yielded two other types of fossil fish incisor teeth which can also be referred to the family Sparidae (see Caldwell, 1957: 153, for a

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detailed discussion of teeth in this family, and the choice of eligible genera within the family).

The first form of the recent finds, and apparently the most common of all three in the deposit, are best assigned to the genus *Diplodus* Rafinesque. There are 11 of these teeth in the University of Florida Collections (UF 6587), measuring 1.8 to 2.2 mm. in greatest width. I have described and illustrated modern teeth of this genus (Caldwell, 1957: 154). Although their bases are broken, all of the fossil teeth possess the remnant of a buttress at the base of the inner surface (Figure 1). Also like modern *Diplodus* teeth these fossils have a smooth cutting edge which is strongly slanting upward toward one corner, and they are somewhat rectangular in anterior aspect above the buttress. Though similar to the incisors of modern *Archosargus probatocephalus* (W a l b a u m), these fossil ones are more strongly incurved in lateral profile—more like those of *Diplodus*—and in anterior profile are broader in relation to their height above the buttress than are those of *A. probatocephalus* (see Caldwell, 1957: 155 and Figures 20-21). Two species of *Diplodus, D. holbrooki* (Bean) and *D. argenteus* (Valenciennes)[2], are presently known from Florida, but their teeth are apparently identical, and no specific name is suggested for the fossils. *Diplodus* is less likely to be found in fresh water than *Lagodon* (see Caldwell, 1957: 154), and the presence of these teeth in the deposit strongly indicates a marine origin for the sparid teeth, and thus the representation in the deposit of two time periods and ecological conditions.

Figure 1. Fossil fish incisor tooth referred to the genus *Diplodus* of the family Sparidae. Line indicates 1 mm.

[2] In citing a single author I follow Bailey (1951: 249).

In the second type of sparid incisor tooth recently found in the deposit the bases are also broken, but enough remains to indicate that they were buttressed as those described for *Diplodus*. Their cutting edges are smooth and only slightly slanting toward one upper corner, and the teeth are square in anterior profile above the buttress (Figure 2). In this squareness they are unlike modern *Diplodus* and *A. probatocephalus* teeth, but are similar to those of *A. rhomboidalis* (Linnaeus) and *A. pourtalesii* (Steindachner), (see Caldwell 1957: 155). However, they are not as strongly incurved in lateral profile as those of these latter species, and though a few may be entire (Caldwell, 1957: 155 and Figure 22), most of the incisor teeth of *A. rhomboidalis* and *A. pourtalesii* have concavely lunate or slightly serrated cutting edges. While these fossils clearly belong to the family Sparidae, they can not presently be ascribed to a particular genus —the nearest modern incisor-toothed types apparently being those found in *A. rhomboidalis* and *A. pourtalesii*, neither of which is known from fresh water (Caldwell, 1957: 155). There are 7 of these fossil teeth (UF 6588), measuring 1.8 to 2.4 mm. in greatest width.

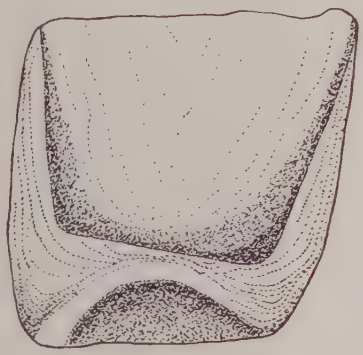

Figure 2. Fossil fish incisor tooth referred to the family Sparidae. Line indicates 1 mm.

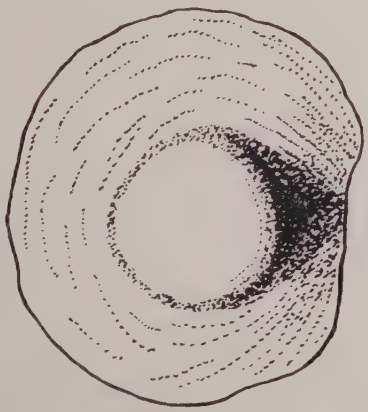

Figure 3. Fossil fish molariform tooth referred to the family Sparidae. Line indicates 1 mm.

In addition to the three types of incisors, the Haile locality has

produced six sub-circular molariform teeth (UF 6589) 2.1 to 2.7 mm. in greatest diameter. These teeth are of the type associated with the incisor teeth in members of the family Sparidae. Most of these molariform teeth are smooth on their upper surface, but several have distinct, rounded, teat-like projections (Figure 3) which are found on a few of the molariform teeth in some individuals of the genera *Lagodon, Diplodus,* and *Archosargus* Gill. Thus, while none of these fossil molariform teeth can be ascribed to a particular genus—since those of the above three named genera are so variable, within the same limits—they do add weight to the identification of the fossil incisor teeth as sparid, and provide further evidence that all three genera may be represented in the deposit.

I wish especially to thank Walter Auffenberg, of the University of Florida, for making available the fossil teeth reported here; for many suggestions made during the study; and for his critical review of the completed paper. The comments on the manuscript made by William W. Anderson, Frederick H. Berry, and Jack W. Gehringer, all of the United States Fish and Wildlife Service at Brunswick, Georgia, were most helpful.

Literature Cited

AUFFENBERG, WALTER

1955. Glass lizards (*Ophisaurus*) in the Pleistocene and Pliocene of Florida. *Herpetologica,* 11(2): 133-136.

1957. A new species of *Bufo* from the Pliocene of Florida. *Quart. Journ. Fla. Acad. Sci.,* 20(1): 14-20.

BAILEY, REEVE M.

1951. The authorship of names proposed in Cuvier and Valenciennes' *"Histoire Naturelle des Poissons." Copeia,* 1951(3): 249-251.

CALDWELL, DAVID K.

1957. The biology and systematics of the pinfish, *Lagodon rhomboides* (Linnaeus). *Bull. Florida State Mus., Biol. Sci.,* 2(6): 77-173.

GOIN, COLEMAN J., and WALTER AUFFENBERG

1955. The fossil salamanders of the family Sirenidae. *Bull. Mus. Comp. Zool.,* 113(7): 497-514.

A NEW FISH OF THE GENUS *OPHIOSCION*, FAMILY SCIAENIDAE, FROM CARIBBEAN COSTA RICA

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The fishes of Caribbean Central America, and particularly Costa Rica, are imperfectly known. Thus it was of special interest and significance to make a detailed study of a small collection of fishes recently received by the University of Florida Collections from Tortuguero, a small village on the northern coast of Costa Rica. The species and notes on the ecology of the fishes in this collection will be discussed in detail elsewhere (Caldwell, Ogren, and Giovannoli, MS). Among the marine fishes were two specimens of an undescribed species of the genus *Ophioscion* of the family Sciaenidae. This species may now be known as:

Ophioscion costaricensis, new species

Figure 1

Diagnosis

An *Ophioscion* (as defined by Schultz, 1945) with a very small eye—4.8 and 5.0 percent of standard length in specimens 110 and 117 mm. in standard length. Dorsal fin count X—I, 22-23; anal fin II, 9; 49 pored scales in lateral line; and 8 + 1 + 14 gill rakers on the first gill arch.

Description

To facilitate comparisons between *O. costaricensis* and the other Atlantic species of *Ophioscion*, as discussed by Schultz (1945), I have taken most of the measurements he included. These are presented as part of the description of *O. costaricensis* and appear in Table 1, along with the measurements based on Schultz for *O. microps* (Steindachner) and *O. brasiliensis* Schultz, its two closest relatives. Other, more subjective, characters of *O. costaricensis* are apparent from the photograph of the holotype which appears as Figure 1.

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FIGURE 1. *Ophioscion cumanensis*, new species, holotype, 116.0 mm. standard length, from Tortuguero, Caribbean coast of Costa Rica, Central America.

Characters not obvious from a study of the table and figure are: The ventral profile is nearly straight in the paratype (as figured for other species of this genus by Schultz 1945), and the protruding ventral outline of the holotype is an artifact of preservation. Tip of lower jaw without barbels. Pores on the tip of snout and lower jaw as described and figured for the genus *Ophioscion* by Schultz (1945). Pseudobranchiae well developed. Scales ctenoid. The more dorsal preopercular spines smaller than those nearer lower angle of preopercle; none hooked downward. Skull with cavernous spaces as described for this and other sciaenid genera by Schultz (1945). Teeth in villiform bands in both jaws, the outer ones of the upper jaw enlarged. Second dorsal spine slightly enlarged (heavier than the following ones). Second anal spine enlarged, but not reaching tips of soft rays. Posterior margins of dorsal and anal soft-rayed fins rounded; pectorals pointed. Posterior edge of spinous dorsal fin nearly straight. Mid-rays of caudal fin longest. Tip of filament of first pelvic soft ray reaching to anus; pectoral fins reaching beyond anus. Gill rakers short and slender, the longest equaling diameter of pupil.

Color

In alcohol, pale brown above, lighter below, with numerous tiny dark punctulations on scales except on ventral third of body of the holotype (missing only on most ventral part of body in the paratype—nearly covering the sides). Membranes and rays of dorsal and most of anal fins dusky, the last two anal rays and their membranes clear. Distal edge of spinous dorsal membrane nearly black. Inner ventral fin rays and membranes dusky toward their distal edges; outer rays and membranes dusky nearly to base of fin; filamentous first ventral ray white. Pectoral rays dusky and their membranes mostly clear. Caudal rays and membranes dusky.

Relationships

With the recent revision (Schultz, 1945) of the Atlantic species of *Ophioscion* and the detailed descriptions of the Pacific American forms presented by Meek and Hildebrand (1925) and Hildebrand (1946: 294), the relationships of *O. costaricensis* have a firm basis.

TABLE 1. PROPORTIONAL MEASUREMENTS (EXPRESSED IN HUNDREDTHS OF STANDARD LENGTH) AND COUNTS OF SELECTED SPECIES OF THE GENUS *OPHIOSCION*. THE DATA FOR *O. MICROPS* AND *O. BRASILIENSIS* ARE BASED ON SCHULTZ (1945). THE FIGURES IN PARENTHESES AFTER THE DATA FOR *O. COSTARICENSIS* ARE THE EMPIRICAL MEASUREMENTS IN MM. FOR EASE IN COMPARING ONTOGENETIC RELATIONSHIPS BETWEEN THE SPECIES, THE SPECIMENS ARE ARRANGED ACCORDING TO SIZE.

CHARACTER	*O. microps*		*O. brasiliensis*		*O. costaricensis*	
	A	B	holotype	paratype	holotype	paratype
Dorsal fin rays	XI—I, 21	XI—I, 19	X—I, 22	X—I, 21	X—I, 23	X—I, 22
Anal fin rays	II,9	II,9	II,9	II,9	II,9	II,9
Pectoral fin rays	ii,17-ii,16	ii,16-ii,16	ii,16-ii,17	ii,17-ii,17	ii,17-ii,17	ii,17-ii,17
Pelvic fin rays	I,5	I,5	I,5	I,5	I,5	I,5
Scale rows above lateral line to base of 1st dorsal soft ray	4	4	5	5	5	5
Scale rows above lateral line to dorsal origin	5	5	5	5	5	5
Vertical scale rows above lateral line	50	51	46	46	48	49
Pored scales in lateral line	—	—	45	46	49	49
Zig-zag scale rows around caudal peduncle	18	18	17	17	16	17
Scale rows between lateral line and anal origin	8	7	7	7	7	7
1st arch gill rakers	11+1+18	11+1+19	8+1+13	9+1+13	8+1+14	8+1+14
Preopercular spines	—	—	—	[9]	9	10
Standard length (mm.)	60.3	66.3	77	89	109.6	116.6
Head length	33.2	32.1	33.8	33.2	30.5 (33.4)	32.1 (37.4)
Greatest body depth	31.5	30.2	32.5	30.8	30.0 (32.9)	32.4 (37.8)
Diameter of eye	6.5	6.6	7.5	7.4	5.0 (5.5)	4.8 (5.6)
Snout length	8.6	9.9	9.2	8.8	8.7 (9.5)	8.3 (9.7)
Front of upper lip to rear tip of maxillary	11.9	11.3	12.2	11.8	10.2 (11.2)	10.9 (12.7)

Postorbital head length	19.1	18.5	18.8	18.4	18.8 (20.6)	19.0 (22.2)
Bony interorbital width	11.3	10.4	9.7	9.1	11.4 (12.5)	11.6 (13.5)
Base of last anal ray to midcaudal base (caudal peduncle length)	24.9	26.8	22.1	23.6	24.2 (26.5)	24.6 (28.7)
Least depth caudal peduncle	10.1	9.9	10.0	9.6	9.9 (10.8)	10.6 (12.4)
Length of second dorsal base	35.6	33.2	32.5	31.2	34.0 (37.3)	34.0 (39.7)
Length of anal fin base	12.6	12.5	12.5	12.9	12.0 (13.2)	12.2 (14.2)
Third dorsal spine length	19.8	19.6	17.5	——	16.2 (17.8)	18.2 (21.2)
Second dorsal spine length	13.4	14.0	12.3	11.8	11.5 (12.6)	11.4 (13.3)
Second anal spine length	18.6	18.1	16.2	13.8	15.6 (17.1)	15.7 (18.3)
Longest pectoral ray	25.7	21.1	24.4	22.5	25.0 (27.4)	27.1 (31.6)
Longest pelvic soft ray	23.7	23.1	25.1	25.8	22.2 (24.3)	24.9 (29.1)
Pelvic spine length	13.3	12.4	12.1	11.7	11.7 (12.8)	12.0 (14.0)
Longest midcaudal ray	—	—	26.0	23.0	28.4 (31.1)	27.8 (32.4)
Longest gill raker	2.7	2.7	3.6	2.8	2.8 (3.1)	3.1 (3.6)
Tip of snout to origin of spinous dorsal	38.1	36.9	37.1	36.5	35.5 (38.9)	36.9 (43.1)
Tip of snout to anal origin	66.8	65.4	68.3	70.8	66.2 (72.6)	67.2 (78.3)
Tip of snout to pelvic insertion	—	—	35.4	35.5	32.5 (35.6)	33.4 (38.9)
Tip of snout to pectoral insertion	33.3	32.1	34.4	33.7	30.3 (33.2)	31.8 (37.1)

The species of this genus are all quite similar in appearance, with the separations often based on relatively minor characters. Hildebrand (*loc. cit.*) has pointed out that the number of rays in the anal fin is constant within a species and that "the differences of a single ray in this fin apparently may be regarded as of specific importance." Schultz (1945) relied heavily on this character in separating the 7 Atlantic species in his key, although he found a single specimen of *O. panamensis* Schultz with an "off" anal soft-ray count. *O. costaricensis* differs from all other Atlantic species of the genus except *O. brasiliensis* and *O. microps* in having a II, 9 anal fin count. According to Meek and Hildebrand (1925), only *O. vermicularis* (Günther) of the Pacific species has a II, 9 count. *O. costaricensis* differs from *O. vermicularis* in having fewer dorsal soft rays; fewer lateral-line scales; the mid-caudal rays longest; a smaller eye; and other characters apparent from descriptions of the two forms. *O. costaricensis* differs from *O. brasiliensis*, as defined by Schultz (1945), in having a much smaller eye; greater bony interorbital; a slightly higher lateral-line count; a slighter longer second dorsal fin base, pectoral fin, and midcaudal fin rays; in addition to other minor proportional characters shown in Table 1. *O. costaricensis* differs from *O. microps*, as discussed by Schultz (1945), in having fewer dorsal spines; apparently averaging a slightly higher dorsal soft-ray count; fewer gill rakers on both the upper and lower limbs of the first gill arches; more scales between the lateral line and the base of the soft dorsal fin; fewer zig-zag rows of scales around the caudal peduncle; a smaller eye; shorter anal spine; a slightly lower soft dorsal fin; and other minor proportional characters shown in Table 1. Aside from the character of anal fin count, *O. costaricensis* differs from all other American species of *Ophioscion* in combinations of characters given in the descriptions of other species in Schultz (1945), Meek and Hildebrand (1925), and Hildebrand (1946).

When Schultz's key (1945: 126) to the Atlantic species of *Ophioscion* is utilized, *O. costaricensis* will insert in couplet three, between its closest relatives *O. brasiliensis* and *O. microps*, from which it has been distinguished in the above discussion. When the key to the Panamanian species of the genus is utilized (Meek and Hildebrand, 1925: 636), *O. costaricensis* would be identified as the Pacific form, *O. typicus* Gill, from which it differs in having more anal soft-rays and a smaller eye.

Holotype

University of Florida Collections (UF) 5831, 116.6 mm. in standard length, found dead on the open sea beach by Larry H. Ogren on July 15, 1956, at Tortuguero, Caribbean Costa Rica, Central America (latitude 10°34′ N., longitude 83°32′ W., approximately 52 miles northwest of Limon, Costa Rica).

Paratype

UF 5830, 109.6 mm. in standard length, found with the holotype.

Remarks

Named *costaricensis* in honour of the country upon whose shores the specimens were collected.

The proportional measurements on *O. costaricensis* were made with the use of dial calipers calibrated to tenths of a millimeter. The last soft ray of the dorsal and anal fins is split to its base and was counted as one.

Acknowledgments

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Literature Cited

CALDWELL, DAVID K., LARRY H. OGREN, and LEONARD GIOVANNOLI

[MS] Systematic and ecological notes on some fishes collected in the vicinity of Tortuguero, Caribbean coast of Costa Rica.

HILDEBRAND, SAMUEL F.

1946. A descriptive catalog of the shore fishes of Peru. *Bull. U. S. Natl. Mus.*, no. 189, xi + 530 pp., 95 figs.

MEEK, SETH E., and SAMUEL F. HILDEBRAND

1925. The marine fishes of Panama. Part II. *Field Mus. Nat. Hist.*, pub. no. 226; zool. ser., vol. 15: xv-xix + 331-707 pp., pls. xxv-lxxi.

SCHULTZ, LEONARD P.

1945. Three new sciaenid fishes of the genus Ophioscion from the Atlantic coasts of Central and South America. *Proc. U. S. Natl. Mus.*, 96 (3192): 123-137, figs. 5-8.

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NOTES ON THE BARRED PATTERN IN THE SHEEPSHEADS, *ARCHOSARGUS PROBATOCEPHALUS* AND *A. OVICEPS*

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U. S. Fish & Wildlife Service
Bureau of Commercial Fisheries
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Brunswick, Georgia

NOTES ON THE BARRED PATTERN IN THE SHEEPSHEADS, *ARCHOSARGUS PROBATOCEPHALUS* AND *A. OVICEPS*

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In his original description of *Archosargus oviceps,* Ginsburg (1952) discusses the variation in color pattern of this form and its near relative, *A. probatocephalus* (Walbaum). The only substantial character he found (with which I concur) to distinguish the two forms is the number of dark bars on the side. Not counting the incomplete head bar, *A. oviceps* has five (Figure 1A), and *A. probatocephalus* has six (Figure 1B).

Ginsburg suggested that the geographic dividing line between the forms lies in the Gulf of Mexico in the vicinity of the Florida-Alabama line (*A. oviceps* to the west and *A. probatocephalus* to the east). The specimens I have examined from Destin, Florida, some 70 miles east of the state line, are primarily 5-barred, and those from Cedar Key, Florida, are mostly 6-barred. Joseph and Yerger (1956: 136), in anticipation of the placing of Ginsburg's *A. oviceps* in synonomy (personal conversation with Yerger in March, 1958), listed *A. probatocephalus* from Alligator Harbor, Franklin County, Florida, although their specimen was of the 5-barred type. Alligator Harbor lies about 175 shoreline miles east of Destin, and about 115 shoreline miles northwest of Cedar Key. Thus the break between the two primary color variants must lie somewhere between Cedar Key and Alligator Harbor.

Analyzing the two forms, Ginsburg found that of 269 specimens of *A. probatocephalus* he examined, 24 had 6 bars on one side and 5 on the other and 14 had 5 bars on both sides. Since he found these non-6-barred patterns only on specimens 74 mm. (presumably standard length) or smaller, and as all specimens he examined which were 92 mm. or larger had 6 bars, he felt that " . . . an obvious and plausible explanation . . . " for the non-6-barred condition in *A. probatocephalus* " . . . is linked with a lethal factor which results in the failure of such variants to reach some size, much less to reach adulthood." He thus postulated a " . . . physiological barrier . . . " as one of the isolating factors between the two forms. Of 78 speci-

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mens he examined of *A. oviceps*, two (14 and 35 mm.) had the asymetrical pattern—none had 6 bars on both sides. He also suggested that the physiological barrier was operating here and it must be presumed that a 6-barred individual from the range of *A. oviceps* would also be considered a "variant" and subject to the barrier. Although the possibility of sympatric species, or of allopatric species exhibiting parallelism in all age groups (see below), cannot be discounted, Ginsburg obviously did not subscribe to these possibilities and considered his species a member of an allopatric species-pair, neither of which exhibits parallelism in the adult or sub-adult stages.

Ginsburg also discussed a geological barrier possibly related to past geologic history. However, it is not the aim of this paper to discuss this, nor should it be considered a revision of the group—though a broad nomenclatorial postulation is presented below. Rather, its purpose is to report specimens which would fall into Ginsburg's classification of "variants" and yet which have reached maturity, or at least adult or sub-adult size. Some of the variations reported below are much more bizzare than those discussed by Ginsburg, and still others undoubtedly exist. I agree with him that the particular banded pattern is almost surely constant once established in an individual.

The bar-pattern-variants may conveniently be divided into two groups—those which are known from the range of 6-barred *A. probatocephalus* and those from the range of 5-barred *A. oviceps*.

In the first category the only variants which I have seen are ones with 5 bars on both sides (Figure 1A). In the 5-barred condition the bars are somewhat wider than those found on 6-barred fishes.

The first of these (University of Florida Collections 2269), 272 mm. in standard length, was collected on January 10, 1954, at Cedar Key, Levy County, Florida. The second (UF 2281), 221 mm. in standard length, was taken at Blind Pass, between Sanibel and Captiva islands, Lee County, Florida, on February 3, 1954. This locality is about 240 shoreline miles south of Cedar Key. The specimen was a fully mature, running ripe, male. Dr. Victor G. Springer, of the Florida State Board of Conservation, writes that he has noted three variant specimens from the range of the 6-barred *A. probatocephalus*. All are from or off the Tampa Bay region of the west coast of peninsular Florida about midway between Cedar Keys and Blind Pass. These records are summarized

as follows: (1) February 14, 1958, one, with a 6-5 pattern, 230 mm. in length, from about 8 miles offshore between Indian Rocks Beach and Clearwater. (2) February 24, 1958, one, with a 5-5 pattern, 80 mm. in length, from Cross Bayou Canal, Pinellas County. (3) February 24, 1958, one, with a 5-5 pattern, 81 mm. long, from the southern part of Boca Ciega Bay, Pinellas County. Dr. Springer wrote that all were taken in company with 6-6 barred individuals. Mr. Thomas R. Hellier, Jr. (who was searching for such variants for me), told me that he observed a 5-barred individual, approximately 225 mm. in standard length, in a commercial fish house at Jensen Beach (near Ft. Pierce), Martin County, lower Atlantic coast of Florida. The fish had been taken locally. I photographed another individual with 5 bars in the tanks of Marine Studios, Marineland, Florida, in September, 1954. I was told by the curator, Mr. F. G. Wood, that this fish, estimated to be about 125 mm. in standard length, was caught in the vicinity of St. Augustine, St. Johns County, Florida.

The variants observed from within the range of *A. oviceps* are all from Destin, Okaloosa County, Florida—near the eastern end of the range of this form. All of the fishes noted below were living in the tanks of Florida's Gulfarium at nearby Ft. Walton Beach. Lengths are estimates, but all fish were full adult or sub-adult in size. I have photographs of all of these (from which the accompanying figures were taken), but the officials of the Gulfarium were understandably loath to part with their hard-caught specimens—even for scientific purposes. I first observed all but the one illustrated as Figure 1 F on July 16, 1956. All had been collected from the same spot (under the U. S. Highway 98 bridge over East Pass) and on such closely spaced dates that a single local resident population was presumed to have been sampled. It is therefore of special interest to note that all of the bar patterns illustrated in Figures 1 A to 1 E were taken from precisely the same local population. These captive individuals were still living in July, 1957, when the oddly marked individual illustrated in Figure 1 F, taken from the same locality, was first observed.

Individuals with six bars on both sides (Figure 1 B) were not infrequently encountered at the Gulfarium. I observed 6, all longer than 350 mm. standard length. Hildebrand (1955: 211) also found this variation in specimens he examined at Port Isabel, Texas, about 940 shoreline miles west of Destin. In addition, he noted

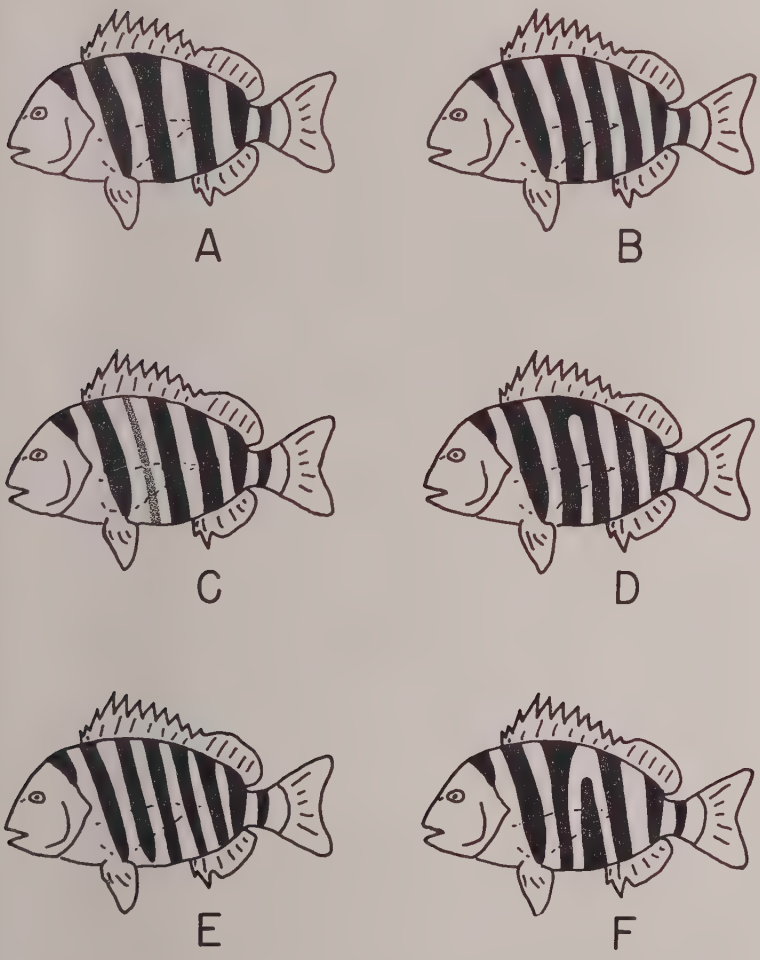

Figure 1. Semi-diagramatic representation of some variations in bar pattern in the black-barred sheepsheads, *Archosargus probatocephalus* (Walbaum) and *A. oviceps* Ginsburg. See text for explanation of figure. (General body outline after Smith, 1907: Plate 14).

them south of Texas—on the Mexican coast. He listed a small locally-caught 6-barred individual in the collection of the Institute of Marine Science of the University of Texas, at Port Aransas, approximately 815 shoreline miles west of Destin. I have seen this specimen and can confirm his bar count. Another Gulfarium specimen, approximately 450 mm. in standard length, had 6 normally-sized and placed bars on the left side (Figure 1 B). The pattern on the right side also consisted of 6 bars, but the second full bar was much narrower (half the width of the others) and less intense (Figure 1 C). Another individual, approximately 350 mm. in standard length, had 6 bars on each side, but the second and third full bars on the right side were joined dorsally by an equally intense cross-bar (Figure 1 D). Still another large fish, about 450 mm. in standard length, had 6 bars on its left side and 7 on the right (Figure 1 E). With regard to this variation it is thought-provoking to note that Smith (1907 :301), in describing the color of *A. probatocephalus*, in North Carolina, stated that the body has "6 to 8 broad, black, nearly vertical bands." Even counting the incomplete head band, thus giving a count of 7 for the nominal form *A. probatocephalus*, the "8" would infer that he observed at least one 7-barred specimen, in addition to 5-barred specimens inferred by his count of "6" (counting bars as described earlier in this paper). The last variant observed at the Gulfarium is one with 6 bars on the right side, and the pattern illustrated in Figure 1 F on the left. This fish was about 275 mm. in standard length.

Hildebrand (1955: 211) notes that he found a specimen with the asymetrical (6-5) bar pattern from the Campeche banks off the west coast of Yucatan, Mexico.

In black-barred forms of *Archosargus,* one bar is located near the base of the caudal fin and two others are positioned below the origin and end of the dorsal fin. These 3 and the incomplete bar on the head apparently are stable in position (Figure 1). The bars between those below the origin and end of the dorsal fin are the ones that have been reported to produce the variation (Figure 1).

It becomes evident that the character of color pattern in the black-barred sheepsheads can be unstable, whether genetically or ecologically influenced, and it seems quite likely that thorough analysis of large series of sheepsheads may prove *A. oviceps* synonymous with *A. probatocephalus*, as suggested by Hildebrand (1955:

212); or more likely, since the two nominal forms do exhibit the reasonably constant single character of bar number, of subspecific rank—at least for the sake of nomenclatorial convenience. *A. aries* (Valenciennes)[2], a South and Central American form apparently distinguished only by having narrower bars (6) than *A. probatocephalus* (Ginsburg, 1952: 96) and teeth, possibly also falls into this pattern complex, as suggested by Eigenmann and Hughes (1888: 69).

In addition to the above-described variations in bar pattern, the following aberrantly-colored specimen of *A. probatocephalus* has been loaned to me by Dr. Springer. At his request, this specimen will be deposited in the fish collection of the United States National Museum.

The fish is 218 mm. in standard length and to all intents might be superficially called an albino. However, since there is some melanophoric pattern still evident in the preserved fish, and since Dr. Springer wrote that as a fresh specimen "there was much color present as carotenoids," this individual might be more properly termed a golden variant. Hubbs and Springer (1957: 308) have reported such a color variation in *Gambusia hurtadoi* Hubbs and Springer from fresh water in Mexico. Dr. Springer has kindly allowed me to include here his color notes taken from the sheepshead when fresh. It was collected by T. Schaum on November 15, 1957, in Tampa Bay, Florida (more precisely, south of Bunce's Bridge—second bridge south of St. Petersburg on the Sunshine Causeway, U. S. highway 19). Dr. Springer wrote: "Life coloration. Overall body color bright golden yellow with scale margins pinkish. Spines of dorsal pinkish, posterior dorsal yellow with base pinkish. Caudal: dusky on center rays, upper and lower rays pinkish orange; posterior margin light yellow. Anal spines pinkish as is anal base; rays yellow. Pelvic: pink-yellow; pectoral same as pelvic, but with a black blotch at bases of upper rays and in axil. A poorly defined humeral spot on one side. Lips pink; forehead pink and gold; breast light yellow, belly pink; iris golden." The pectoral blotch and the humeral spot are present in normally pigmented black-barred sheepsheads, but are obscured by the black bars. This golden specimen has very light traces of 6 complete bars, in addition to a faint head bar. In addition to this specimen, Dr. Springer stated that he had had reports of two additional "golden"

[2] In using the single author name I follow Bailey (1951: 249).

color-variants, but that he had been unable to see them and so listed them only tentatively.

In addition to acknowledging the cooperation received from those persons cited within the body of the text, I wish to thank Messrs. William W. Anderson, Frederick H. Berry, and Jack W. Gehringer, all of the United States Fish and Wildlife Service at Brunswick, for many helpful comments regarding the present paper. An earlier version was examined by Drs. John C. Briggs, Archie Carr, and J. C. Dickinson, Jr., all of the University of Florida, and their criticisms were most helpful in developing the final manuscript.

Literature Cited

BAILEY, REEVE M.

1951. The authorship of names proposed in Cuvier and Valenciennes' "Histoire Naturelle des Poissons." *Copeia,* 1951(3): 249-251.

EIGENMANN, CARL H., and ELIZABETH G. HUGHES

1888. A review of the North American species of the genera Lagodon, Archosargus, and Diplodus. *Proc. U. S. Nat. Mus.* 10 (for 1887): 65-74.

GINSBURG, ISAAC

1952. Eight new fishes from the Gulf coast of the United States, with two new genera and notes on geographic distribution. *Jour. Washington Acad. Sci.,* 42(3) : 84-101.

HILDEBRAND, HENRY H.

1955. A study of the fauna of the pink shrimp (*Penaeus duorarum* Burkenroad) grounds in the Gulf of Campeche. *Publ. Inst. Mar. Sci. Univ. Texas,* 4(1) : 169-232.

HUBBS, CLARK, and VICTOR G. SPRINGER

1957. A revision of the *Gambusia nobilis* species group, with descriptions of three new species, and notes on their variation, ecology, and evolution. *Texas Jour. Sci.,* 9(3) : 279-327.

JOSEPH, EDWIN B., and RALPH W. YERGER

1956. The fishes of Alligator Harbor, Florida, with notes on their natural history. *Florida State Univ. Studies, No.* 22, *Papers from the Oceanogr. Inst., No.* 2, pp. 111-156.

SMITH, HUGH M.

1907. The fishes of North Carolina. Raleigh, North Carolina Geological and Economic Survey, II: xi + 453 pp.

REPORTS OF STANDING COMMITTEES

COMMITTEE ON INTERNATIONAL RELATIONS

W. F. Carbine

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REPORTS OF STANDING COMMITTEES

COMMITTEE ON INTERNATIONAL RELATIONS

W. F. Carbine

Your committee is happy to report a continuation of cordial international cooperation for the care of fisheries exploited jointly by the various nations. Steady progress has been made but there still remains much to be done.

International fishery commissions have been in operation for many years and we would like to express our opinion as to their importance, as follows:

1. They provide for an exchange of ideas and techniques by administrators, fishermen, businessmen, and biologists. The research requested and designed by them for obtaining answers to mutual problems meets mutual needs, eliminates national bias and prejudice, and is apt to be equally acceptable to all parties without dispute.

2. They provide for a better understanding of international fishery problems and allow closer working relationships between professional fishery workers and the fishing industry.

3. They make possible larger budgets for specific fisheries work than would be possible without international cooperation.

4. They allow more effort to be put into a specific fisheries job because each country has a vital stake in the results. Methods, techniques and equipment can be standardized; the best available used or new ones developed.

5. They require prompt publication of information and data pertaining to the fishery, because the Commissioners require such to make recommendations and regulations.

6. International Commissions provide the means for management of international fisheries on the high seas. Without international agreement and mutual adoption of sound regulation, many valuable research recommendations for improving fishing would not be put into effect. Commissions, in addition to creating goodwill, provide practical and legal means for management of high seas fisheries. There are now several action programs to which member nations represented on Commissions have contributed manpower and resources to solve fishery problems of mutual concern.

Although the principal duty of the commissions is to provide practical and legal means of managing the high seas fisheries, perhaps the most gratfying and yet undramatic development of international cooperation is the exchange of ideas possible under such an arrangement. M. C. James,

research coordinator for the Pacific Marine Fisheries Commission, and a member of this committee, has contributed the following illustration:

> The development of a new offshore gill net salmon fishery created alarm in the Pacific Coast states. The Pacific Marine Fisheries Commission, at its annual meeting, sparked action to bring about a coastwide ban on this fishery before it became well established. To be effective, such a prohibition should be applied equally by the three states, by Canada and by the Federal government in Alaska. Under the auspices of the U. S. Department of State, a Conference on Coordination of Fisheries Regulations took place at the end of February. Agreement was reached on the form and nature of the action required and, by the opening of the fishing season, three states had passed concurrent legislation. Canada had acted administratively, and the U. S. Government had the situation under control in Alaska.
>
> Thus, a common conservation measure was made effective in a minimum of time over a vast area by informal procedures which bypassed the sometimes cumbersome machinery of normal international negotiations. The groundwork was laid for a further fitting together of Canadian and U. S. regulations and research if such action becomes desirable.

Because we believe the international commissions have been so successful, it is suggested that the States enter into interstate compacts, commissions or agreements for solving fishery problems, river basin developments, navigation, flood control, and other similar problems of mutual interest.

I would like to take this opportunity to acknowledge gratefully the assistance of the members of the Committee in the preparation of this report; especially Dr. Stillman Wright, Mr. William M. Terry, Fred E. Taylor, Lloyd O. Royal, and other individuals in position to comment on international fisheries.

Following are some highlights and latest developments in International fisheries:

International Fishery Agreements

International Pacific Halibut Commission.—The high-seas fishery for halibut off the western coast of North America has been under scientific investigation and observation for more than 30 years. For the past 25 years, halibut fishing has been effectively regulated by the Commission. The halibut stocks, which under unrestricted fishing, had declined to a low, and commercially unprofitable level, has been increased through Commission action by more than 50 percent and is taken with about half the former fishing effort. The catch in 1956 was more than 67 million pounds. Major work of restoring the halibut fishery has been done but there can be additional yield when the Commission discovers how to permit it without endangering stocks. The research required is now being planned.

International North Pacific Fisheries Commission.—This Commission, which held its first meeting in February 1954, has devoted itself primarily to three lines of investigation, and has in the past 2 years made gratifying progress.

It will be recalled that the Convention establishes a provisional line separating salmon of North America and Asian origin, and that Japan has agreed to refrain from fishing for salmon east of this line as long as certain conditions are met by the Governments of Canada and the United States. The Protocol to the Convention requires that the Commission undertake an immediate study to determine whether or not this provisional line effects an equitable separation of the two groups of salmon. The United States, Canada and Japan are cooperating in the implementation of a research program drawn up by the Commission. Major elements of the program are tagging of salmon; study of physical characteristics such as body proportions, blood types, infestations by parasites; the marking of downstream migrants; and oceanographic studies. Considerable progress has been made in all phases of the investigation. While the program is primarily concerned with the distribution and migration of salmon, a great deal of information is being obtained on the sea-life of the salmon which will be invaluable to workers in the field of salmon management.

At the request of the United States, the Commission has undertaken an investigation of the king crab stocks of the eastern Bering Sea to determine what, if any, conservation measures may be needed to make possible the maximum sustainable yield from these stocks. The United States and Japan are cooperating in this investigation.

Finally, the Commission is moving forward with the study required by Article III of the Convention to determine whether or not the stocks of halibut, herring and salmon in the eastern Pacific Ocean, which Japan has agreed not to fish, continue to meet the conditions which warrant abstention by Japan. The Commission is required to make its first determination in this regard in 1958. The United States and Canada have provided the Commission with information regarding these stocks. This information is now under study in the Commission.

The Inter-American Tropical Tuna Commission.—The Commission has continued its investigations along the lines last reported to the Society; compilation and analysis of catch statistics and related data, tuna biology and life history, oceanography and tuna ecology, and biology, ecology and utilization of baitfishes. These investigations are carried out from headquarters in California and from field stations in Panama and Costa Rica. Among the most significant of the results of this work are the Commissions conclusions regarding the effect of the fishery upon the abundance of the tuna stocks. It will be recalled that in its 1954 report the Commission reported that analysis of historical data on catch-per-day's fishing and catch-per-day's absence had led it to the conclusion that (1) the fishery for yellowfin tuna was sufficiently intense to affect very markedly the average abundance of the stocks, and (2) there is no clear relationship between fishing intensity and the abundance of skipjack tuna. Yellowfin and skipjack tuna together make up about 84 percent of the catch, yellowfin

comprising about 46 percent of the catch. Continued studies of this type have confirmed these conclusions and have indicated that the level of intensity reached in 1952 and 1953 may be near that corresponding to maximum sustainable yield of yellowfin. The evidence indicates, however, that a considerable increase in the average yield of skipjack would be possible with increased exploitation.

Fishing effort decreased somewhat in 1954 and 1955 and the rate of exploitation was considerably below the level of maximum sustainable yield. Both fishing effort and catch rose somewhat in 1956, but the fishery remained at a level below that corresponding to the maximum sustainable yield.

As a result of this research, the Commission has found it possible to make an estimate of the status of each of the tropical tuna species, taken in the aggregate, and thus is in possession of a basic management tool. The Commission is currently giving particular attention to the problems involved in formulating and applying regulatory measures against the day when fishing effort increases to the point where a limit must be imposed if the maximum sustainable yield is to be obtained.

Research on the status of important baitfish stocks indicates that with regard to the anchoveta, the most important species, the population is subject to rather large variations in abundance not associated with the amount of fishing. It appears that in each of the major areas, at current levels of fishing effort, variations in environmental factors are of greater importance in determining abundance than the effects of fishing.

Interim Convention on Conservation of North Pacific Fur Seals.— After protracted negotiations, which began in November 1955, representatives of the Governments of Canada, Japan, the USSR and the United States signed the Interim Convention on Conservation of North Pacific Fur Seals in Washington, February 9, 1957.

In brief, the Convention continues: (1) prohibition of pelagic sealing first enforced internationally under the terms of the 1911 Fur Seal Convention, and continued, following the termination of that Convention in 1942, under the terms of an agreement between the United States and Canada: (2) provides for a sharing of the annual kills on the Pribilof and Kommandorski Islands and Robben Island; (3) provides for cooperative research on fur seals by agencies of the four governments to develop a basis for a more permanent agreement; and (4) establishes the North Pacific Fur Seal Commission, composed of one representative from each government. This Commission's primary function will be the planning and coordination of research, and the development of recommendations concerning the level and composition of annual harvest and the methods to be employed in such harvests.

At this writing, the Convention has been ratified by Canada and Japan. Ratification by the USSR and the United States and entry into force of the Convention is expected in the near future.

International Commission for the Northwest Atlantic Fisheries.—The ICNAF is a compact of 10 nations which fish the Grand Banks of the Northwest Atlantic, where millions of pounds of food fish are produced each year. Research on northwest Atlantic fishery problems is carried out by the staffs of fishery agencies of each member nation. All nations contribute to the research effort, although understandably some do much more than others. Research is planned by the Standing Committee on Research and Statistics, which routinely meets annually. Especially close liaison has been accomplished between United States and Canadian researchers because of mutual interests in ICNAF.

Mesh regulation research has occupied the Commission almost since its inception. This work has culminated in adoption of regulations by all 10 member nations for the conservation of cod and haddock stocks on the Grand Banks off United States, Nova Scotia and Newfoundland. This regulation specifiies the minimum size for meshes in nets used for cod and haddock fishing, thereby releasing young fish and taking full advantage of growth before capture. In fact, a double benefit has resulted because the new, larger mesh nets have proved more efficient for the capture of the older, marketable fish. It is estimated that 30 percent more haddock have been produced on Georges Bank since use of the larger mesh nets than would have been possible had the regulation not been adopted.

ICNAF has been responsible for much important research which otherwise would not have been accomplished. The release of statistics, the coordinated planning of research and the free exchange of information resulting from the fairly frequent meetings have all contributed to knowledge of the Grand Banks fisheries.

Great Lakes Fishery Commission.—In April 1956, representatives of Canada and the United States convened for the first meeting of the Great Lakes Fishery Commission. This organization was established in accordance with a Convention signed by Canada and the United States in September 1955. The Commission is concerned with formulating and implementing a comprehensive program for eradicating or minimizing the sea lamprey populations in the Convention area, and to coordinate research programs designed to make possible the maximum sustained productivity of the stocks of fish in the Convention area.

The establishment of the Commission made possible an improvement in operation and in coordination and planning of sea lamprey control and research in the Great Lakes. The Commission contracted with the U. S. Fish

and Wildlife Service to execute the lamprey program in United States waters and with the Fisheries Research Board of Canada as the agency in Canadian waters. The entire sea lamprey control program is financed by the Commission, using funds appropriated by the two countries. The fishery research programs on the Great Lakes, although coordinated by the Commission, are directly financed by the national, state, or university organizations performing the work.

Sea lamprey control has been confined to Lakes Superior and Michigan. At the end of the 1956 lamprey spawning season, all streams entering Lake Superior known to harbor lampreys were under control. Lake Michigan should be under complete control by the spring of 1958. Lamprey control work to cover Lakes Huron, Erie and Ontario, will proceed with utmost speed.

Sea lamprey research activities have been directed toward improving existing electrical sea lamprey control devices, developing electronic devices for leading desirable fish out of lethal electrical fields, and testing specific lamprey larvicides. Tests of larvicides have progressed to the point where actual "pilot" treatment of streams is planned for the early fall of 1957. The installation and operation of 7 experimental direct-current devices in combination with alternating current control barriers proved successful in reducing fish mortality.

With the closing of the control network on Lake Superior, the Commission is immediately faced with the question of whether the stocks of lake trout remaining are sufficiently abundant to permit recovery of the fishery. It is expected that no noticeable decrease in lampreys will occur before 1959 or 1960. The lake trout will be under heavy attack during this period and the deposition of spawn during the next 4 or 5 years will be low or negligible in some instances. It is agreed by all cooperators on the Great Lakes that some hatchery planting of lake trout will be necessary. Research has indicated the size of fish to be planted and the places and time of planting, and the fact that planting can be started a year or two after control is completed. Plans are now being prepared by the Commission for the planting program that will be recommended to the federal and state governments.

Other research on the Great Lakes consist of studies on the hydrography of the lakes, tagging studies to establish population identities, movements, distribution, densities and fluctuations, adequate biological sampling and improved statistics of the commercial catch.

The Work of the International Law Commission. After some six years of work, the International Law Commission, an agency of the United Nations, has completed its task of codification and progressive development of international law on the Regime of the Sea. In its report to the General Assembly covering the work of its Eighth Session, March 1 - July 1956, the Law Commission proposes some seventy draft articles dealing

with various aspects of the law of the sea. Of interest to fishery people are the fishery articles, the continental shelf articles, and the articles on the territorial sea. All of these have a direct bearing upon the welfare of United States marine fisheries.

The fishery articles, twelve in number, are in effect a legal system designed to permit the greatest possible freedom of fishing on the high seas, and at the same time providing for the conservation of the living resources of the high seas. By conservation the Law Commission means the aggregate of the measures rendering possible the optimum sustainable yield from the resources of the seas so as to secure a maximum supply of food and other marine products. To achieve this end, the Law Commission; (1) reaffirms the right of fishing on the high seas by the nationals of all States; and (2) subjects this right to certain limitations necessary for the purposes of conservation. Thus it would impose on all States the obligation to adopt measures necessary for the conservation of resources which their nationals exploit. It would require two or more States whose nationals are exploiting the same resources to cooperate with a view to adopting by agreement necessary conservation measures. (It will be recognized that this is a procedure which the United States and Canada have for years made voluntary use of with great success in connection with the Pacific halibut and the sockeye salmon of the Fraser River.) The Law Commission would also require that in certain circumstances the fishermen of one state would be obliged to observe the conservation measures adopted by other states. It recognizes the special interest of a coastal state in the continuing productivity of the marine resources in the high seas adjacent to its coast, and would ensure the coastal state of the right to participate on an equal footing in any program of investigation and regulation of such resources, whether or not the nationals of the coastal state exploit the resource. It would also grant the coastal state the right, in certain prescribed circumstances, to adopt regulations which would be applicable to the nationals of all states fishing such resources. Finally, the Commission proposes a system of obligatory arbitration of disputes arising under the fishery articles.

To a great extent, these articles incorporate philosophy which the United States has been guided by for years. The application of this philosophy involves substantial departures from existing international law and practice, but in most regards may be considered a step forward.

For the most part, the Law Commission's articles on the Continental Shelf reflect the position taken by the United States in 1945 in the so-called Truman Proclamation on that subject. The articles define the shelf as the seabed and subsoil of the submarine areas adjacent to the coast but outside the area of the territorial sea, to a depth of 200 meters, or, beyond that limit, to where the depth of the superjacent waters admits of exploitation of the natural resources of the said areas; and grant to the adjacent coastal state sovereign rights over the shelf for the purpose of exploring for and exploiting its natural resources. It is with regard to the meaning of the

term "natural resources" that fishery interests become involved. The Law Commission has taken this term to include, in addition to the mineral resources, living forms permanently attached to the seabed, but not bottom fish and other fish which, although they live in the sea, occasionally have their habitat at the bottom of the sea or are bred there. There is not unanimity of opinion on this definition in the Law Commission or among governments. Representatives of a number of governments have proposed that the natural resources should include the entire marine flora and fauna which lives in a constant physical and biological relationship with the seabed and the continental shelf. In the past, the United States has taken a position on this question of natural resources identical with that of the Law Commission.

The Commision's articles on the breadth of the territorial sea reflect the absence of agreement in the world today on this matter. It recognizes that practice is not uniform on the matter. It considers that international law does not permit an extension of the territorial sea beyond twelve miles, but takes no decision on the question, recommending that it be settled by an international conference.

In its report to the General Assembly, the Law Commission noted the fact that there was great diversity of opinion on what was and what was not accepted international law on the sea, and recommended that the General Assembly summon an international conference of plenipotentiaries to deal with the matter. After some debate, the General Assembly adopted this recommendation and decided to convene a conference in March 1958 at either Rome or Geneva.

Preparations for this conference are now going forward in this Government. The Departments of State and Interior and other interested agencies are studying the articles, and in consultation with the interested public are preparing United States' position the various questions.

International Pacific Salmon Fisheries Commission, 1956—The International Pacific Salmon Fisheries Commission has been conducting scientific investigations of the Fraser River sockeye salmon runs for 19 years and has been recommending regulations for commercial fishing for 11 years. Through the application of scientific principles to the management of this international sockeye fishery the Commission has had outstanding success in the fulfillment of its obligations. Since 1946 it has been required that Commission regulations provide equal division of the catch of Fraser River sockeye insofar as practicable. In the past 11 years United States fishermen have caught 18,008,893 sockeye and Canadian fishermen 18,421,157 sockeye, a cumulative difference in equality of about 0.5 percent for the entire period. Commission regulations and management principles, together with removal of river obstructions, have almost doubled the commercial catch of sockeye over the past 8 years. In the 4 years ending 1956, the total catch of sockeye was 17,469,899 fish, whereas in the preceding 4 years it was

8,885,768 fish. Research has indicated the intimate relationship between sockeye salmon and their fresh water and ocean environment. Such research has enabled the Commission to rehabilitate barren streams by transplantations of eggs from suitable donor stocks. In addition, it has provided the basic principle for protection of the fishery from possible adverse effects of multiple water use such as water pollution and power dams. Protection of the fishery from such adverse effects requires increasing attention by the Commission each year. Management of the fishery is also becoming more complex due to increased numbers of fishing gear and the increased efficiencies and effectiveness of the gear.

Foreign Aid Program

The International Cooperation Administration continued to carry out programs of technical assistance in the development and conservation of fisheries in several foreign countries. Although fish add only a small fraction of the total supply of food in the world, they are important for contributions of protein, minerals, and vitamins. It has been estimated that fish supply, on the average, only 10 calories and 1.3 grams of protein per capita per day for the world population. Marine resources in general can be exploited further without danger to the supply. Additional consumption is particularly important in part of Asia, where the predominantly rice diet require additives for proper balance.

During the past year or somewhat more, fishery programs were in force in 10 countries. The countries and principal technicians assigned to them are listed below:

El Salvador	Charles B. Wade
Peru	Robert O. Smith
Liberia	Charles Jones
Pakistan	Leroy S. Christey
India	Ole J. Heggem
Indonesia	Edwin H. Dahlgren
Thailand	Milton J. Lobell
Viet-Nam	Robert J. Schoettler
Taiwan	William A. Ellison
Korea	Harry E. Timmis

An important part of the program is that of training students and adminstrators of foreign countries in the United States so that they can assume responsibility for continuation of projects started by American technicians. Each year, several participants received instructions or in-Service training and return home to make practical use of their new knowledge and skills. In the last few months of 1957, trainees will arrive from Indonesia, Thailand, Korea, India, and Pakistan, to add to the growing body of competent technicians in various fields of industry, biology, and management.

The U. S. Fish and Wildlife Service works closely with the International Cooperation Administration in carrying out the foreign aid program. The Service assists particularly in recruiting technicians for assignment abroad, in providing technical support, and in arranging suitable training facilities for foreign students.

International Events in Central and South America.—The 1956 meetings of the Gulf and Caribbean Fisheries Institute and the International Game Fish Conference were held in Nassau, Bahamas. The 1957 meetings are both scheduled for November in Miami Beach. At the Nassau meetings reports were presented on the sport fishing situation in the Virgin Islands, game-fish of Bermuda, pelagic game fishes of Chili, the commercial fishing industry in Cuba, the research conducted on the marine fisheries of Yucatan, Mexico, and means of improving the Caribbean fisheries.

In Venezuela, government and private organizations are promoting the development of the fisheries by training marine scientists for this work. Two students recently completed training in the United States. Panama, in an effort to develop her shrimp fishery, has obtained an FAO expert to make a study of the fishery. Mexico is increasing its interest in the shrimp fishery and plans to set up a research agency. The Shrimp Association of the Americas, which is a trade association including the United States and Mexican shrimp producers, has been active in supporting fisheries work and has established two fellowships to support graduate students in fisheries at the University of Miami.

The shrimp fishery on the Tortugas grounds near Key West has recently become an international one with the advent of Cuban trawlers. In recognition of this, some preliminary discussions have been held concerning the desirability of an international treaty.

Your Committee urges this Society to continue to take the lead in supporting the practice of seeking the solution of international problems through international investigations.

ACCUMULATION OF RADIOACTIVE MATERIALS BY FISHERY ORGANISMS

WALTER A. CHIPMAN
Radiobiological Investigations
U. S. Fish and Wildlife Service

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The Marine Laboratory, University of Miami

Accumulation of Radioactive Materials by Fishery Organisms

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We are now living in a period in which there is tremendous expansion in the use of atomic energy. There is great interest in possible hazards to man of the radioactivity associated with the release of the energy of the atom. Of considerable concern is the contamination of man's environment with radioactive materials. Such materials added to the atmosphere, soil, and natural waters may be taken in by man and levels of radioactivity may be built up in the body sufficient to be damaging. In marine environments radioactive contaminants may accumulate in seafood organisms and affect their utilization or availability.

In discussing radioactive materials we need to consider that these materials are radioactive isotopes of chemical elements. In most cases the atoms that compose a chemical element differ in mass and those of like mass members, the isotopes, are present in definite ratios. For instance carbon, wherever it is found in nature, is composed almost 99 per cent of carbon atoms of mass number 12 and about one per cent of carbon atoms of mass number 13. With the advent of man-made isotopes of carbon with other mass numbers, for example carbon-14, which is radioactive, it is possible to have carbon compounds in which the isotopic ratio is changed by inclusion of radioactive atoms. For the most part, the chemical and physiological processes of the body make use of elements to form compounds without discrimination as to their isotopic composition. Thus a radioisotope may be incorporated into the body tissues of marine plants and animals if present in their environment.

Living tissues accumulate chemical elements to different degrees. It is well known that certain elements, such as calcium and strontium, are concentrated in skeletal structures, such as bone and shell. Other elements are present in greater amounts in certain soft tissues and organs. Although maximum levels of concentration of an element exist, the elements composing the compounds of the body are constantly being replaced. Some compounds are broken down and reformed rapidly; others only slowly. If radioactive isotopes are included with the other isotopes of the element involved in the metabolism of marine organisms, an accumulation of radioactivity can result.

Radioisotopes may be added to a marine environment from the use of nuclear weapons and from the various operations required for the use of nuclear reactors. Some disposal may be made in coastal waters of a variety of radioisotopes used in industry, research, and medicine. They may be grouped into two general categories based on their origin. One includes the fission products resulting from the fission of uranium-235 and the other the radionuclides of elements

produced from induced nuclear changes, generally from neutron bombardment resulting from the fission process.

Contamination of a marine environment from nuclear warfare can be from fission products and from induced radionuclides. Although there was an addition of fission products to the sea water from the testing of nuclear weapons in the Pacific Ocean, large contributions to the total radioactivity of certain fish were found to be from the non-fission product, zinc-65, and of certain molluscs from cobalt-60 (Weiss *et al.*, 1956). Many other induced radionuclides were also present in the fish and shellfish.

In the normal operations concerned with the use of nuclear reactors only insignificant amounts of radioactive materials are released to natural waters. Many reactors are cooled with water and the primary coolant water may contain radioactive materials. These may be radioisotopes of the elements normally present in water or present as corrosion products. They become radioactive from close association with the high neutron flux of the reactor core. Some fission products may be present if ruptures occur in the coverings of fuel elements. However, generally the primary coolant is contained within a closed system in which the heat is transferred through heat exchangers to a secondary coolant. Only through leaks within the heat exchangers would radioactive materials be passed to the secondary coolant. Small amounts of fission products are included in the waste effluents of chemical plants engaged in the reprocessing of irradiated and spent fuels. In a few instances low-level radioactive wastes from such plants are released into coastal waters.

It is the purpose of this paper to discuss the accumulation of radioactivity by marine fish and shellfish when fission product radionuclides and other radioisotopes are present in sea water.

For the most part the discussion is based on the experimental work of the Radiobiological Investigations of the Bureau of Commercial Fisheries carried on at the Beaufort, North Carolina, laboratory. Some of the findings were described previously (Chipman, 1958) and details of many of the results are reported in the scientific literature or will be published shortly.

Accumulation of Fission Products

We may first consider the accumulation of radioisotopes of the fission products. We have measured the uptake of radioactivity by plankton, fish, and shellfish following the addition of mixed fission products of nearly one year of age to sea water or administered in foods. We have made radiological analyses of the accumulated radioactivity to determine the radioisotopes responsible for the activity. In order to further understand accumulation patterns, we have tested the uptake and accumulation of several of the individual radionuclides of such mixtures.

Table 1 shows some of the radionuclides produced in the fission of uranium that may be considered as biologically important and the per cent they contribute to the total radioactivity after different periods of time. The great majority of those having a significant contribution from twenty days up to about one year of age are those of the rare earth elements or those having chemical characteristics similar to rare earths. The importance of strontium-90 and cesium-137 in aged fission products is apparent.

TABLE 1

PER CENT OF TOTAL RADIOACTIVITY CONTRIBUTED BY CERTAIN FISSION PRODUCTS OF BIOLOGICAL INTEREST AT DIFFERENT TIMES AFTER FISSION.[1]

	20 days	90 days	1 year	3 years	10 years	20 years
Sr^{89}	5.0	10.5	2.7	—	—	—
Sr^{90}-Y^{90}	—	—	3.7	17.4	44.0	48.0
Y^{91}	5.6	12.5	3.8	—	—	—
Zr^{95}	5.9	14.7	7.2	—	—	—
Nb^{95}	2.3	18.0	14.7	—	—	—
Mo^{99}	1.3	—	—	—	—	—
Ru^{103m}	4.4	7.2	0.8	—	—	—
Rh^{103}	4.2	7.0	0.8	—	—	—
Ru^{106}-Rh^{106}	—	—	4.9	6.0	—	—
I^{131}	5.6	—	—	—	—	—
I^{132}	1.1	—	—	—	—	—
Cs^{137}-Ba^{137m}	—	—	2.9	13.6	36.0	45.0
La^{140}	13.9	1.8	—	—	—	—
Ba^{140}	12.0	1.6	—	—	—	—
Ce^{141}	9.7	8.5	—	—	—	—
Pr^{143}	12.0	11.2	2.6	—	—	—
Ce^{144}-Pr^{144}	2.6	12.0	52.8	42.0	—	—
Nd^{147}	5.0	—	—	—	—	—
Pm^{147}	—	—	5.7	19.0	16.0	3.4
Sm^{151}	—	—	—	1.1	2.5	2.6

[1]Adapted from data of Hunter and Ballou (1951). Reference, Chipman (1958).

The availability of radionuclides for uptake by marine fish and shellfish is dependent in part on their chemical nature and physical state when present in the sea water. When fission products of about one year of age are added to sea water, the greater part of the radioactivity will be present in the form of particles. As seen in Table 2, only radioisotopes of strontium and cesium remain as the important fission products of mixtures of this age in solution. The nature of the ruthenium compounds is difficult to predict, but in our tests we had precipitation of ruthenium when employing ruthenium-106 at the pH of sea water.

Not only may there be a formation of particles, but there is also a marked adsorption of many radionuclides to the surfaces of particles. There is a great abundance of particles in natural sea water, especially in certain inshore waters. This adsorption of radionuclides to both living and non-living particles in sea water is of considerable significance in discussing the fate of radioactivity added to marine environments.

Accumulation by plankton

In the sea the primary concentrators, the photosynthetic plants, take chemical elements directly from the water. For the most part, these plants are the minute single-celled algae, the phytoplankton. Because of their small size they offer tremendously large surfaces for adsorption. An accumulation of radioactive materials by these forms may be passed to marine animals through the food webs of the sea.

In the Pacific Ocean following the testing of nuclear weapons, high radio-

activity was found in the plankton, the nannoplankton samples having high radioactivity than those composed of larger organisms (Harley, 1956).

TABLE 2

PROBABLE STATE OF CERTAIN FISSION PRODUCTS WHEN PRESENT IN SEA WAT

Particulate	Solution
yttrium-91	strontium-89
zirconium-95	strontium-90
niobium-95	ruthenium-103*
praseodymium-143	ruthenium-106*
cerium-144	cesium-137
promethium-147	

*Questionable

In laboratory culture planktonic algae rapidly take up radioactivity wh fission products are added to the sea water medium. In a very short time nea all the radioactivity of added mixed fission products is associated with the ce In tests with separated fission products we found very great accumulation some radionuclides. These would thus be available in concentrated amounts passage through the food webs to marine animals. There was great accumu tion of ruthenium-106. The rare earth radionuclide, cerium-144, was ac mulated many thousands of times above sea water concentrations as sho from the concentration factors listed in Table 3. Radioisotopes of yttrium markedly concentrated. The experiments indicate that much of the accumu tion of many radionuclides is related to surface areas.

Marine algae may be of little importance in passing certain radionuclides animals. These include the radioisotopes of strontium and of cesium. As s in the concentration factors listed in Table 4, marine species of phytoplank do not concentrate cesium-137 appreciably. Although some species conc trate strontium, many take up only small amounts of radiostrontium added the sea water in which they are grown (Rice, 1956).

With few exceptions the fishes and many other animals are not equipped feed directly on phytoplankton. They depend on other forms which pos mechanisms which allow this type of feeding. An important group of ph

TABLE 3

CONCENTRATION FACTORS OF Ce^{144} FOR VARIOUS SPECIES OF PLANKTONI ALGAE, CALCULATED ON A WET WEIGHT BASIS

Algae	Number of times over sea water concentra	
	After 0.5 hours	After 24 hours
Carteria	314	2422
Platymonas	1843	2127
Nitzschia	518	1970
Thallassiosira	2610	3346
Amphidinium klebsi	3001	4498
Porphyridium	802	3344

plankton feeders is the small animal plankton. These are eaten by small fi which may serve as food for others still larger.

TABLE 4

CONCENTRATION OF CESIUM BY MARINE ALGAE.[1]

Algae	Concentration factor[2]
Bacillariaceae	
Nitzschia closterium	1.2
Amphora sp.	1.5
Nitzschia sp.	1.7
Chlorophyceae	
Chlamydomonas sp.	1.3
Carteria sp.	1.3
Chlorella sp.	2.4
Pyramimonas sp.	2.6
Nannochloris atomus	3.1
Rhodophyceae	
Porphyridium cruentum	1.3

[1]Boroughs, Chipman, and Rice (1957).
[2]The concentration factor is reported as the ratio of Cs^{137} in the algae (wet weight) to that in an equivalent weight of sea water at an apparent steady-state condition.

We have observed that marine copepods and other filter-feeding zooplankton forms do rapidly become radioactive when exposed to sea water in which are suspended radioactive phytoplankton cells and other radioactive particles.

The copepod, *Tigropus californicus,* removed nearly all the radioactive cerium available in the sea water and food giving the animal a high concentration over the water. Likewise, brine shrimp feeding on *Nannochloris* cells containing ruthenium-106 became radioactive from their water filtration. Apparent high concentration factors can result when such accumulation of radioactive food particles can be collected from large volumes of water.

As regards the fission product radionuclides present as particles or associated with the phytoplankton food, the great majority are those poorly absorbed from the digestive tract. Consequently, the accumulation of radioactivity by the filtering zooplankton is related to the presence of radioactive particles on the filtering mechanisms and concentrated within the digestive tract. They fail to accumulate significant amounts of fission product radionuclides in their bodies. When the radioactive particles are no longer available, the accumulated radioactivity of the zooplankton forms is rapidly lost, depending on the time for the clearing of the digestive tract. An example of the rapid loss of accumulated cerium-144 by copepods is shown in Table 5. The accumulation was due almost entirely to a concentration of particles.

TABLE 5

RETENTION OF CERIUM-144 BY THE COPEPOD, *Tigropus californicus* (AVERAGE OF 22 INDIVIDUALS)

Days	Activity c.p.m./copepod	Per cent remaining
0	7103	100
1	227	3.2
2	123	1.7

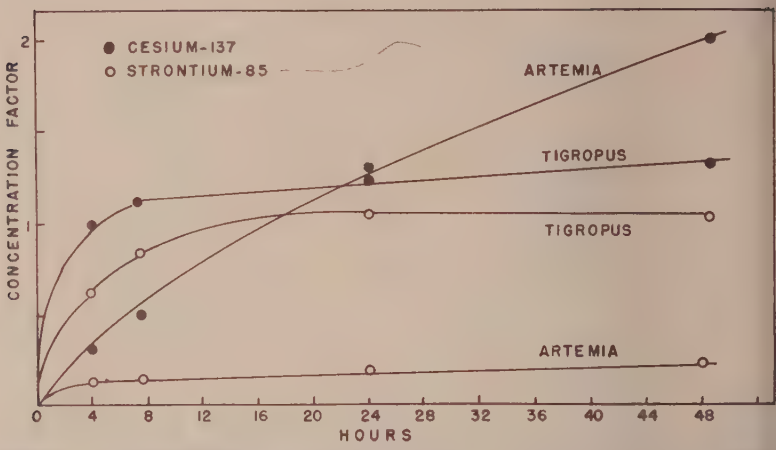

FIGURE 1. Accumulation of cesium-137 and strontium-85 by the copepo *Tigropus californicus,* and the brine shrimp, *Artemia salina,* maintained filtered sea water containing the isotope.

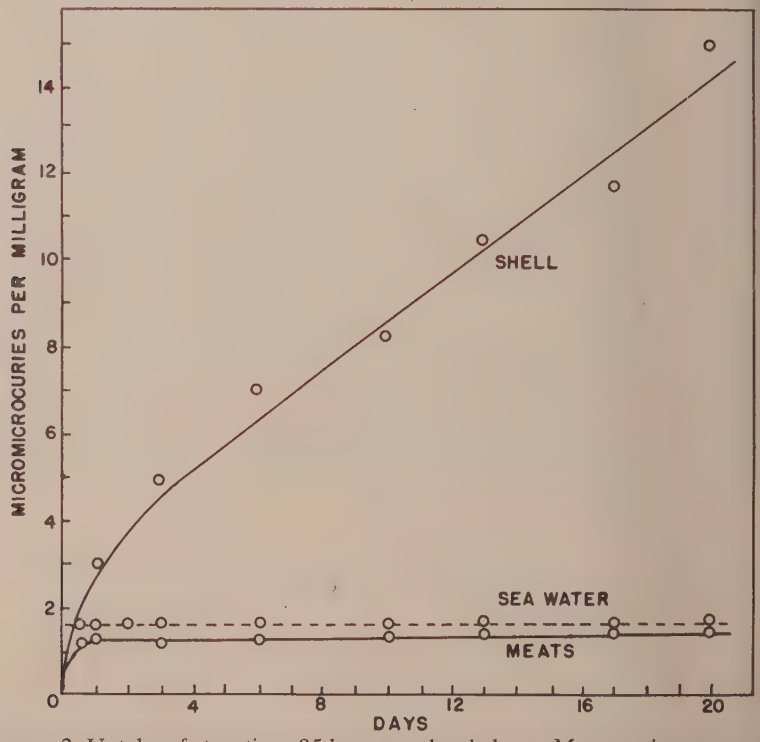

FIGURE 2. Uptake of strontium-85 by young hard clams, *Mercenaria mercenar*

Zooplankton may accumulate radionuclides present in the water in solution. If accumulated to any marked extent, appreciable concentrations may be passed to fishes using these forms as food. Two important fission product radionuclides that may be considered in this connection are strontium-90 and cesium-137. Both are readily taken up from the water and both pass quickly into the body from the digestive tract.

A few species of zooplankton have calcareous structures and may concentrate strontium. Many species do not. We have measured concentration factors for radiostrontium of about one for the copepod, *Tigropus,* and less than one for the brine shrimp, *Artemia* (Figure 1). When phytoplankton food is present, however, a concentration of particles filtered from the water with concentrations of strontium may give an apparent concentration factor somewhat greater than one, particularly if the factor is calculated per unit volume of water disregarding the abundance of phytoplankton cells. Cesium-137 is slowly concentrated through a slow accumulation (Figure 1).

From the foregoing we can see that the zooplankton become radioactive from an accumulation of radionuclides from fission product mixtures, but that they can pass the accumulated radionuclides farther up the food web only while these are within the digestive tract, for the greater part of the radioactivity is due to those that are poorly absorbed from the digestive tract. A concentration of radiocesium in their bodies may permit the transfer of the accumulated radionuclides of cesium to small fish using zooplankton forms as food.

Accumulation by shellfish

Oysters, clams, and scallops are important fisheries organisms which filter large volumes of water and feed on the filtered material. As may be expected, the story of the accumulation of radionuclides of fission product mixtures present in sea water in the form of particles is exactly the same as that of the accumulation by the small animal plankton forms. They concentrate radioactive particles markedly. Often the greater part of the measured accumulation is due to association of particles with body surfaces and their presence in the organs and structures connected with the digestive tract. A great number of fission product radionuclides are not absorbed readily from the tract and are not accumulated or concentrated in body tissues and structures. However, such an accumulation of radioactive particles may be important for purposes of passage through food webs and to man. The fact that man eats the whole soft tissues of oysters and clams allows for the ingestion of many radionuclides that may not be metabolized and incorporated into the tissues of these shellfish.

Strontium radioisotopes are taken up by oysters, clams, and scallops. Uptake is primarily from the water, for there is no great accumulation in their food. The strontium is concentrated in their shells. There is no concentration of strontium in the soft tissues. Figure 2 shows the accumulation of radiostrontium in the shells and meats of hard clams. A concentration factor of less than one over that of the water was found for the meats. Aside from accumulation from the formation of new shell, there is an uptake of considerable magnitude by shells separated from the meats. This accumulation of radioactivity by shells may be of interest in view of the fact that shells are placed on the bottom by oystermen as cultch for the attachment of the young oyster spat.

Cesium-137 is accumulated to relatively high levels by the soft tissues of

shellfish. There is a more rapid uptake by the soft tissues other than muscle, but the highest concentrations are reached in time by the muscles. An example of this differential uptake is shown in Figure 3, which shows the accumulation of cesium-137 by scallops. In ten days the concentration in the adductor muscle of scallops was ten times that of the water and increasing. Actually, the uptake continues for very long periods of time.

We have found that clams concentrate cesium-137 to a greater extent than do oysters, which is in agreement with the difference in their body structure

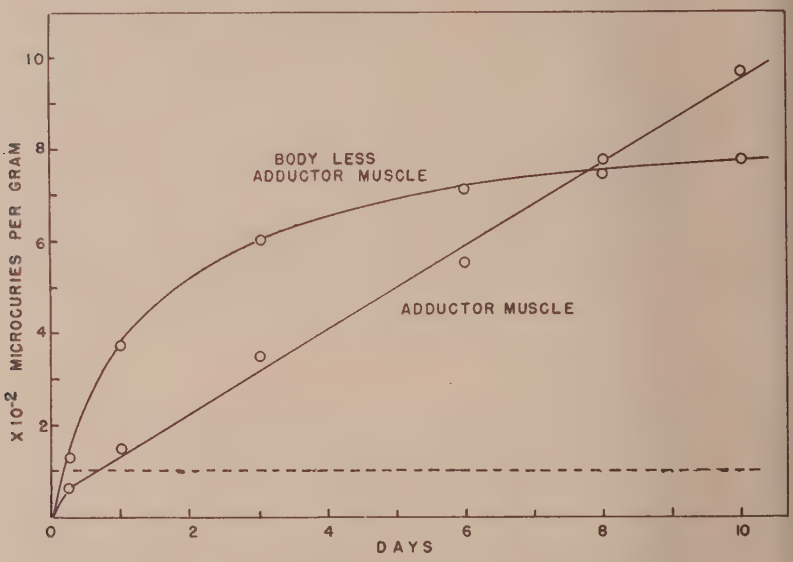

FIGURE 3. Uptake of cesium-137 by the body tissues of the bay scallop, *Pecten irradians*.

as regards muscle tissue. As far as the hazards to humans is concerned from the ingestion of cesium from shellfish, the most hazardous is the scallop, since only the adductor muscle is eaten. Clams would be more hazardous than oysters.

Only small amounts of the radioactivity of mixed fission products administered entered the body tissues of edible crabs and shrimps. Of that that did enter, the greater part was present in the internal organs. Daily oral doses to the blue crab resulted in a gradual accumulation of radioactivity in the shell and in the edible muscle.

In crustacean shellfish, there is an accumulation of strontium radioisotopes in the shell and other calcified structures. Molting results in the loss of the concentrated radioactivity. We have found no concentration of radiostrontium in the muscles.

The radioisotope of mixed fission products that seems to be of most importance in regard to its accumulation by shellfish is cesium-137. It is concentrated

to relatively high levels in the edible meats. In the practice of "heading" of shrimp for market, the accumulated radioactivity of the internal organs and a major part of the shell is discarded. However, relatively high concentrations of radioactive cesium would be present in the marketed portion.

Accumulation by fish

Marine fish, like the invertebrates, take up only small amounts of most of the radionuclides of fission products when taken into the digestive tract. Since the greater part of the radioactivity of a mixture of about a year of age is due to radionuclides of the rare earths and others poorly absorbed through the intestinal wall, very little of the accumulated radioactivity of fish is due to these radionuclides. Table 6 shows the loss of fission product radioactivity from bluefish and croakers at various times after oral administration and the small amounts taken up by the tissues. Croakers given the rare earth radionuclide,

TABLE 6

PER CENT OF ORAL DOSE OF FISSION PRODUCT MIXTURE PRESENT IN FISH AFTER DIFFERENT PERIODS OF TIME

(TEST WITH MFP-1 OF AGE 143-151; 196-199 WITH CROAKERS, AND MFP-1 OF AGE 216 DAYS WITH BLUEFISH)

	Hours after dose	Per cent of oral dose remaining		
		Digestive tract	Body	Total fish
Bluefish (individually)	½	100	0	100
	1	90	6	96
	2	76	2	78
	4	(16	(2	(18
		(14	(5	(19
	8	3	1	4
Croakers (average of 3)	3	43	14	57
	6	56	7	63
	28	5	4	9
	69	2	0.8	2.8
	137	0.4	1.6	2.0

cerium-144, by pipette into the stomach had only about three or four per cent of the radioactivity of the dose in their tissues. Menhaden fed phytoplankton cells containing ruthenium-106 took up only about one per cent of the radionuclide (Table 7).

Although only a small amount of the total radioactivity enters the body of the fish, certain radionuclides are taken up rapidly, and these are markedly concentrated in the fish tissues, particularly in the skeletal structures. Table 8 shows the body distribution of the radioactivity of mixed fission products in bluefish four hours after administration. There was considerable radioactivity in the internal organs and in bone and scales. Repeated daily doses of mixed fission products to fish resulted in marked concentration of strontium-90 in the bones and scales, and a gradual accumulation of radioactivity in the body

TABLE 7

RADIOACTIVITY OF MENHADEN AFTER FEEDING ON PHYTOPLANKTON CELLS CONTAINING Ru^{106}

(TISSUES OF 5 FISH ANALYZED FOR EACH OBSERVATION)

Time in hours	Per cent of dose			
	Gills	Digestive tract and contents	Remainder of fish	Total in fish
0	0.64	92.39	0.76	93.79
2	0.05	80.09	1.00	81.14
4	1.13	21.15	0.53	22.81
8	0.06	7.99	0.34	8.39
16	0.08	8.50	0.56	9.14
32	0.02	5.23	0.22	5.47
64	0.02	1.48	0.26	1.76
128	0.01	0.05	0.25	0.31

muscles. The latter was due to the uptake of cesium-137. The greater part of the radioactivity of the internal organs was due to rare earth radionuclides. However, we have found from repeated doses of the rare earth, cerium-144, to croakers that, although the radionuclide is rapidly concentrated in the liver, the greatest accumulation is ultimately in bone.

There is no concentration of strontium radioisotopes in the edible body muscles of marine fishes. Continuous exposure of small mullets to strontium-85 for thirty days (Figure 4) resulted in a concentration factor over water of only 4.6. In these the greater part of the weight of the fish was due to body muscles, while the greater part of the radioactivity was from accumulation in bone and scales. The body muscles of the killifish (*Fundulus heteroclitus*) had

TABLE 8

DISTRIBUTION OF RADIOACTIVITY IN THE BODY OF BLUEFISH 4 HOURS AFTER ORAL DOSE

(FIVE PER CENT OF DOSE IN BODY. β ACTIVITY MEASURED DAY AFTER ADMINISTRATION)

Part or organ	Gross β radioactivity	
	Per cent of total fish	d.p.s./gm.
Body less digestive tract and internal organs	96.4	331
Muscle		41
Bone		463
Integument		539
Liver	2.0	858
Internal organs other than digestive tract and liver	1.6	438

d.p.s.—disintegrations per second

a concentration factor for strontium-85 of only 0.15 after exposure of the fish to the isotope in sea water for thirty-two days (Figure 5).

Cesium-137 is accumulated in the edible fish flesh and significantly high concentrations can result. The rate of accumulation in internal organs is more rapid than by muscle tissues, but the long-continued uptake by muscles of this radionuclide of long physical half-life can be of great importance when continuously available for uptake. The accumulation of cesium-137 in the body muscles of *Fundulus* is shown in Figure 6. Accumulation was still continuing after an exposure of seventy-two days when the concentration was about thirty-five times that of the water. Fish continuously bathed in sea water containing cesium-137 and eating foods that contain concentrations of the nuclide would gradually accumulate relatively high concentrations in the edible flesh.

Accumulation of Other Radionuclides

Besides the radionuclides of fission product mixtures, we need consider accumulation of certain of the trace elements of sea water. Included in this

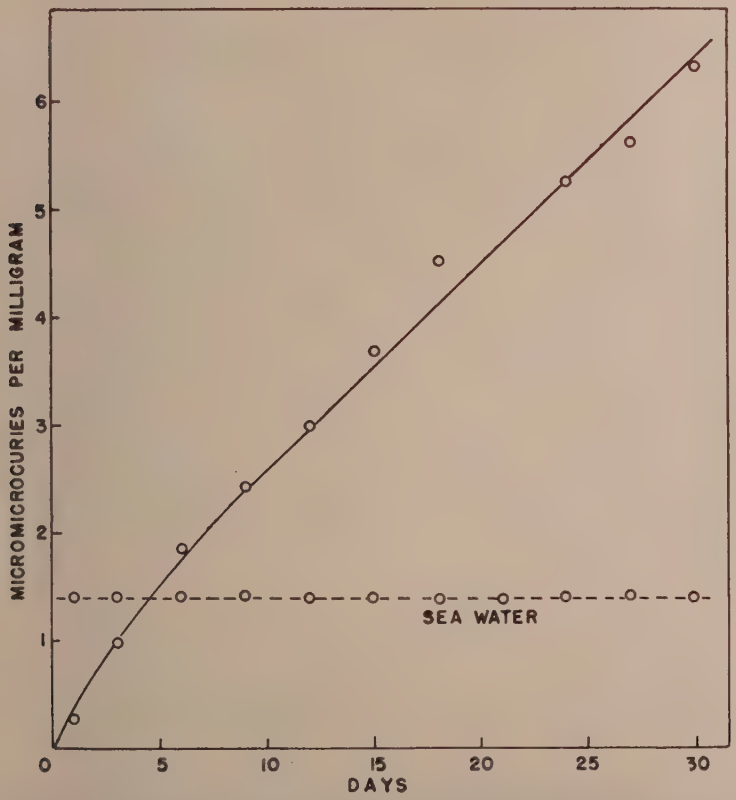

Figure 4. Uptake of strontium-85 by young mullets, *Mugil cephalus*.

category are isotopes of iron, manganese, copper, cobalt, and zinc. To date two of these, radiozinc and radiocobalt, have been studied in our laboratory. A report (Chipman *et al.*, 1958) has been made of the accumulation of radioactive zinc.

When zinc-65 or cobalt-57 are added to sea water in which marine phytoplankton cells are suspended, there is rapid and extensive uptake of the radionuclides. A species of *Nitzschia* was found to concentrate zinc many thousands of times over sea water concentrations. Likewise, phytoplankton cells accumulated cobalt-57 very markedly. It is obvious that, if radioactive zinc or cobalt were added to the sea, high concentrations would be found in phytoplankton and could be passed to animals using these cells as food.

Although these metals are present in sea water in low concentrations, they are markedly accumulated by marine animals. Tests made of the accumulation of radiozinc and radiocobalt by copepods demonstrated that both are taken

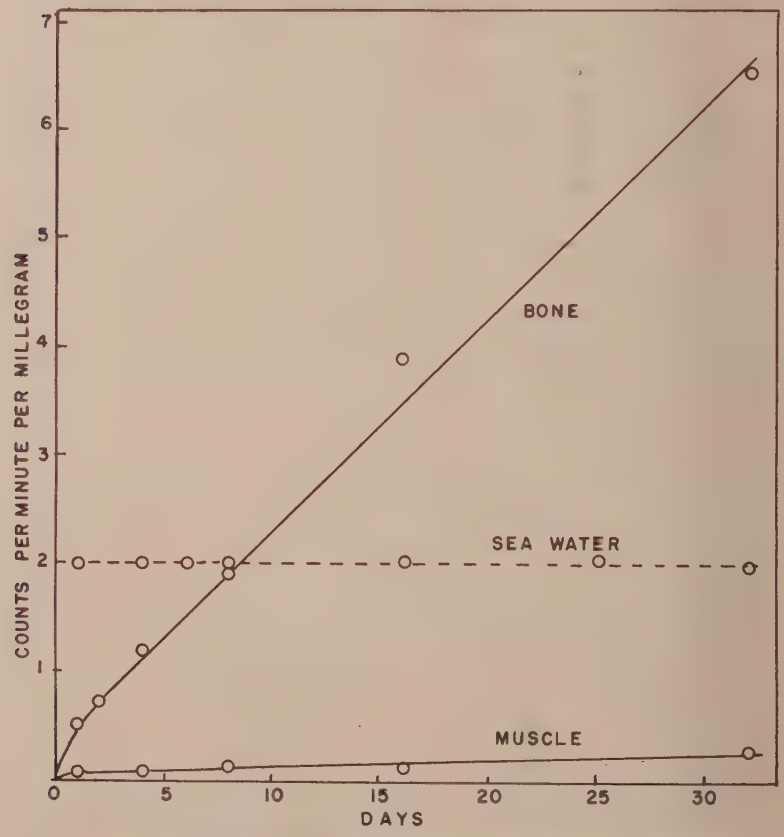

FIGURE 5. Accumulation of strontium-85 in muscle and bone of the killifish, *Fundulus heteroclitus*.

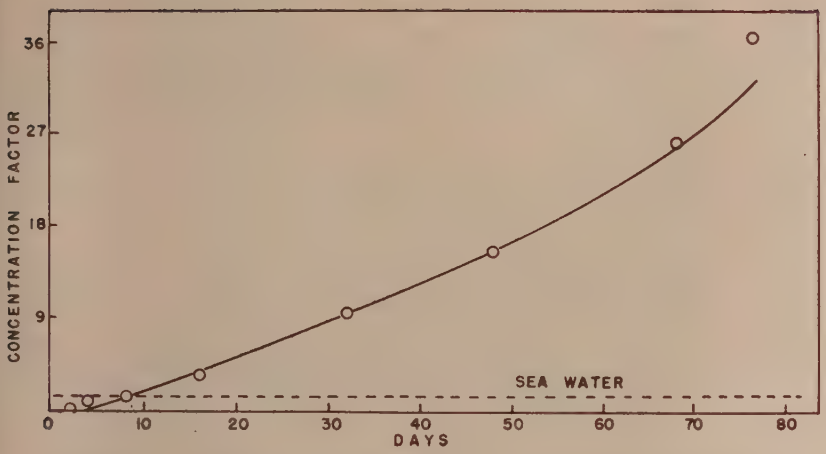

FIGURE 6. Accumulation of cesium-137 in the body muscles of the killifish, *Fundulus heteroclitus*.

up rapidly and to high concentrations, the radiozinc being accumulated to levels over 200 times that of the water in 48 hours with the accumulation continuing. In the same length of time radiocobalt concentration was about fifty times that of the water. Oysters, clams, and scallops concentrate large amounts of zinc, thousands of times more than the sea water. They also concentrate cobalt very markedly. Marine fish were found to take zinc-65 into the body tissues very rapidly with accumulation in the bone, integument, and muscle tissues. High concentrations of zinc-65 were present in the internal organs, notably in the kidneys.

It is apparent that the radioisotopes of the trace metals, zinc and cobalt, added to sea water are quickly taken up and concentrated to high levels by the biota. They are readily transferred through the food web, being passed through the lining of the digestive tract very promptly and accumulated to high levels in the body tissues. Pollution of estuaries or coastal waters with significant amounts of these could create hazardous situations affecting the utilization of our seafood resources.

LITERATURE CITED

BOROUGHS, HOWARD, WALTER A. CHIPMAN, AND THEODORE R. RICE
1957. Laboratory experiments on the uptake, accumulation and loss of radionuclides by marine organisms. *In* The Effects of Atomic Radiation on Oceanography and Fisheries, Publication No. 551, National Academy of Sciences—National Research Council, Washington, pp. 80-87.

CHIPMAN, WALTER A.
1958. Biological accumulation of radioactive materials. Proceedings of the First Texas Conference on Uses of Atomic Energy, pp. 36-41.

Special Publication of the Agricultural and Mechanical College of Texas, College Station, Texas.

Chipman, Walter A., Theodore R. Rice, and Thomas J. Price
1958. Uptake and accumulation of radioactive zinc by marine plankton, fish, and shellfish. Fishery Bull. 135, Fishery Bull. Fish and Wildlife Service, *58:* 279-292.

Harley, John E. (Editor).
1956. Operation Troll. N. Y. Operations Office, U. S. Atomic Energy Commission, Document NYO4656, 37 pp.

Rice, T. R.
1956. The accumulation and exchange of strontium by marine planktonic algae. Limnology and Oceanography *1:*123-138.

Weiss, H. V., S. H. Cohn, W. H. Shipman, and J. K. Gong.
1956. Residual contamination of plants, animals, soil, and water of the Marshall Islands two years following Operation Castle fallout. Research and Development Report, U.S.N.R.D.L.—455, U. S. Naval Radiological Defense Laboratory, San Francisco 24, California, 55 pp.

SIZE SELECTION OF FISH BY OTTER TRAWLS

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Size Selection of Fish by Otter Trawls

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FISHING IS BY NATURE a very selective process. The selection results from the direction of fishing operations and from selective properties of the gear itself. Perhaps the most important of the selective properties of otter trawls is the selection of certain sizes of fish, since it is this property which permits the harvesting of fish stocks at the age which will ensure maximum production. The size selection of fish in otter trawls may be conveniently divided into two categories, extraneous and inherent.

Extraneous size selection is caused by factors other than those associated with the gear itself. The two major sources of extraneous selection are (1) nonrepresentative distribution of the fishing fleet over the total size distribution of the fish and (2) differential availability of different size groups within the fishing region. Selection from the first process will vary in response to seasonal or sporadic changes in either the distribution of the fishing fleet or distribution of the fish stock. Selection by the second process will be affected by changes in fish habits and behavior among areas, seasons and years. Little control can be exercised over either of these factors in management programs, but both are important in the application of biological sampling to the understanding of the structures of fish populations.

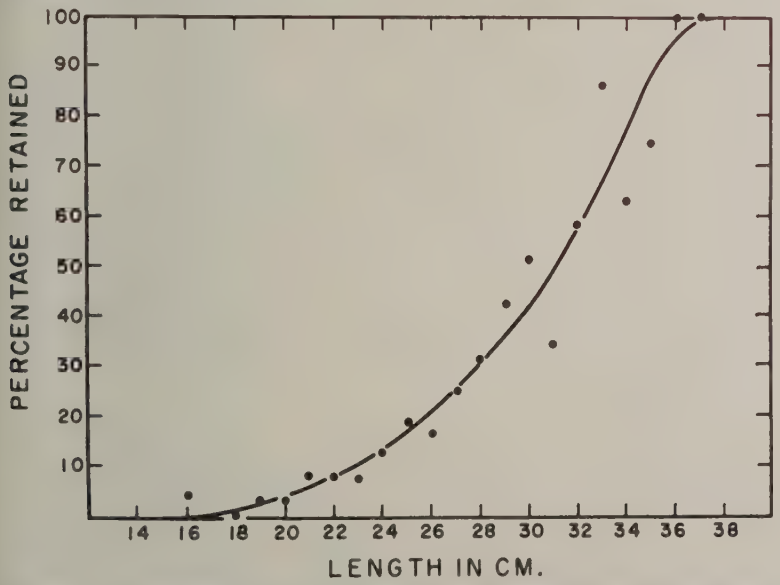

FIGURE 1.—Percentage of various sizes of ocean perch *(Sebastes marinus)* retained by a manila cod end of 132 mm mesh size. Based on experiments conducted by North Atlantic Fishery Investigations.

Inherent size selection comes about through the action of the trawl upon the fish entering the net and, being the most easily controlled, is the type of selection most important in management considerations. Of all the alterable properties of a trawl net the most easily controlled is the size of the mesh. An extensive series of experiments, mostly for the cod end of the net alone, has shown that meshes of trawls do release fish. Moreover, the escapement from a given mesh size has been shown to be inversely related to fish size, with proportionately more small than large fish escaping. The type of size selection occurring in otter trawls is illustrated in Figure 1 by a typical sigmoid selection curve. The size selectivity of a trawl is most commonly defined in terms of its 50 per cent point. This is the fish length which corresponds to the point on the curve at which half the fish entering the cod end are retained and half escape. The 50 per cent point usually increases in direct proportion to mesh size. This relationship is commonly defined by the SELECTION FACTOR, which is the quotient of 50 per cent point (cm.)/mesh size (cm.). Thus, the selection factor is an expression of the fish's capacity to escape. The selection factor varies from species to species and for a particular species varies with the conditions associated with its capture.

Some general knowledge of the type mentioned above was at one time sufficient to provide a basis for management programs. Precise definition of selection was not required because little was known of optimum rates of exploitation. The application of modern statistical methods to studies of fish populations has made precise estimation of optimum size at harvest possible. A demand for similarly precise determinations of gear selectivity has arisen therewith. This need for precision has required the expansion and elaboration of gear selection research in the North Atlantic. This paper will be concerned with the status of otter trawl selection research in the North Atlantic as it has been affected by recent developments.

The establishment of international commissions for management of certain North Atlantic fisheries during the past decade has encouraged an increase in size selection experiments with otter trawls. The resulting accumulation of information has increased our knowledge tremendously, but because of the precision required, disagreements among the results of many experiments have caused great concern. The seriousness of the differences moved the Permanent Commission, dealing with management problems in the Northeast Atlantic, to establish an *Ad Hoc* Committee to consider variations in results. The committee analyzed all available data in order to recommend certain selective standards for otter trawls. For a few species it was possible to choose a single selection factor. For many of the important species, however, the selection factor could be defined only in general terms. These results have been published by the Permanent Commission (1956).

The International Commission for Northwest Atlantic Fisheries (ICNAF), meanwhile, was meeting with similar problems. A summary of haddock selectivity data is shown in Figure 2 (from Graham, 1952) to illustrate the variations in results obtained for a single species of concern to ICNAF. The extent of differences is well demonstrated at a mesh size of approximately 3-3/4 inches where the 50 per cent point varies from 25 cm. to 43 cm. and the resulting selection factor varies from 2.6 to 4.5. Variations such as these render selection data difficult to apply to management programs.

The increasing concern over size selection problems on both sides of the Atlantic resulted in a meeting of gear selection experts from ICNAF, the Inter-

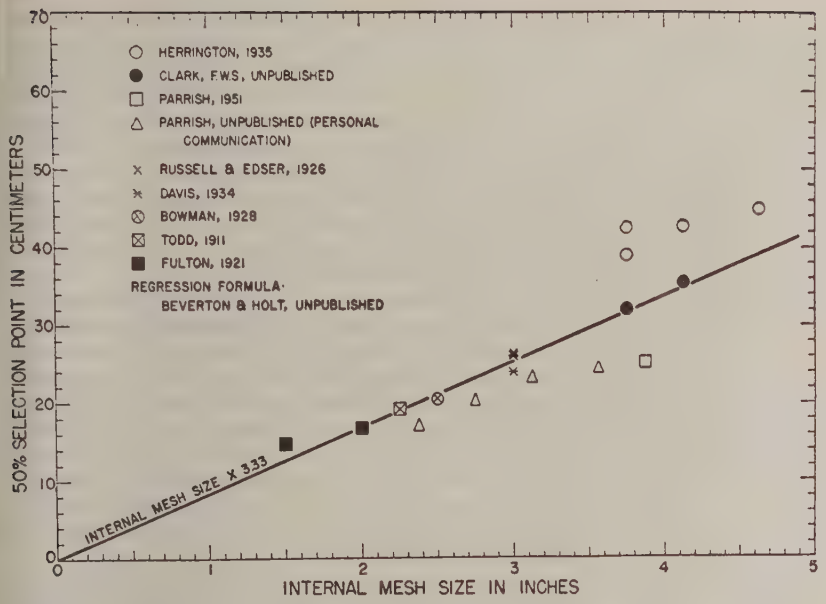

FIGURE 2.—Relation of size of mesh to 50 per cent retention size of haddock.

national Commission for the Exploration of the Sea (ICES), and the Food and Agriculture Organization of the United Nations (FAO) at Lisbon, May 27 to June 3, 1957. At the Joint Meeting, working parties were established to consider, among other matters, the factors of importance in the variations among gear selection results. The deliberations of the working parties demonstrated the complexity of the situation and indicated fruitful avenues of research that could be followed to provide a better understanding of gear selection processes. The results of this Joint Meeting[1] are used as a basis for the following discussion. The working parties were primarily concerned with results of otter trawl selection studies, the majority of which dealt with selection in the cod end.

It was brought out at the meeting that the variations in results can be attributed to either experimental causes or substantive causes. The experimental variations are those deriving from the manner of conducting the experiments and do not arise from real differences in the selective action of the trawls.

A number of experimental methods for determining the selection of sizes of fish by otter trawls are in use, each with its own peculiar sources of variation. The cover method involves the application of small mesh netting over various parts of the trawl to actually trap the escaping fish. A second method is the trouser trawl method, in which two cod ends of different mesh size are attached to the same net. The selectivity of the larger mesh is estimated by comparing the catches of the two cod ends. A third method, which may be called the replicate-haul method, involves the comparison of catches of two separate nets, towed

[1]The report of the Joint Meeting and the papers presented have not yet been published. The author has drawn freely upon the manuscripts in the following pages.

either in alternate series from one vessel or at the same time by different vessels.

The cover method provides the most precise results. Its use, however, is attended by a considerable amount of danger in that if improperly applied the cover can block the meshes and prevent the escapement of fish, thus giving erroneous results. Other disadvantages are that it may restrict the flow of water through the trawl, thereby altering the selective properties of the net, or may be seen by the fish and thereby discourage their escape, or may allow fish to return to the cod end after having once escaped. This method, although effective for the cod end if properly used, cannot easily be employed on the broad surfaces of the net or on its underside. In any event, the effect of the cover should be tested preliminary to the conduct of the experiment.

The other methods listed involve the comparison of the catch of different nets. The best of these is probably that of towing two nets simultaneously from boats fishing as near together as possible, or towing two trawls from the same vessel, as has been done with shrimp beam trawls and scallop drags. The problems inherent to this type of sampling arise from the non-random manner in which the fish are distributed (see Taylor, 1953). The trouser trawl method (two cod ends of different mesh sizes) is less useful because of the abnormality of its construction and a tendency for the two cod ends to catch different amounts of fish. The lowest of the selection values illustrated in Figure 2 were obtained with the cover method and the highest with the alternate tow and trouser methods; the correct values were found to lie in between.

Even with the experimental error accounted for, considerable variation in results may remain, owing to substantive factors. These are real differences which may be attributed to the type of trawl used and the conditions of its operation. The deliberations at the Joint Meeting brought out many important causes of substantive differences in selection research. These differences were shown to be associated with such things as length of tow, size of catch, type of twine used in the netting, and differences in the distribution of meshes of various sizes within the cod ends.

Varying the length of tow has been shown to alter the selection factor considerably. Experiments conducted to investigate the effect of length of tow on the escapement of haddock, for instance, show the selection factor to vary from 3.0 for 20 minute tows to 3.4 for 80 minute tows. Variations in size of catch of haddock in the cod end have been shown to alter the 50 per cent point by as much as eight cm, the higher 50 per cent point being associated with lower catches.

Comparison of results of many experiments have shown that the type of twine used in cod ends is an important factor. At a cod end mesh size of 60 mm, for example, silver hake *(Merluccius bilinearis)* have been shown to have a selection factor of approximately 2.5 for manila, 2.8 for cotton and 3.2 for nylon twine. The higher selection factors apparently result from more flexible twines.

Non-random distribution of mesh sizes in the cod end have been shown to be an important factor in haddock escapement. Meshes at the aft end of a cod end are stretched by the weight of the catch being hoisted aboard and will gradually increase in size over the meshes at the forward end as the cod end continues in use. Results from experiments with special covers have demonstrated that 70 to 90 per cent of cod end escapement takes place in the terminal five to six feet. Systematic differences in mesh size within the cod end must, therefore, be considered in order to interpret results properly. A demonstration of this effect is

provided by one experiment in which a nylon cod end having an average mesh size of approximately 123 mm was tested first in a normal position with the larger mesh aft, and then reversed to put the small mesh aft. In the normal position a selection factor of 3.5 was obtained; with the cod end reversed a selection factor of 3.1 was obtained.

In measuring the meshes of nets certain factors must be given consideration. Of particular importance are the extent to which the mesh is stretched and the particular dimension measured. It is evident that in comparing results of experiments the same dimensions of meshes must be compared. Less evident, but of equal importance, is the problem of stretching the mesh with a standard force. Meshes, of course, must be stretched to some extent in order to measure them accurately. Different instruments and methods may provide different amounts of stretch and, therefore, alter the resulting measurement.

When designing selection experiments the application of the results to the fishery must be thoroughly considered. The following questions are the sort which should be considered in applying results: Are the fish being damaged in escaping through the meshes? Is there an important amount of escapement through the forward parts of the trawl? Have results been obtained for the proper towing speed, twine type, catch size, and so forth? Have proper specifications of the gear been established? What systematic variation is there apt to be within distributions of meshes of given average size?

Another problem of importance involving the application of results is that concerning the type of relationship that exists between mesh size and fish escapement. The establishment of this relationship is necessary in order to predict, from experiments on a few mesh sizes, the size of the fish that will escape from any size of mesh. A simple linear relationship between mesh size and fish size has been accepted as being valid for various species. Certain recent experiments have shown, however, that this relationship cannot be applied to all

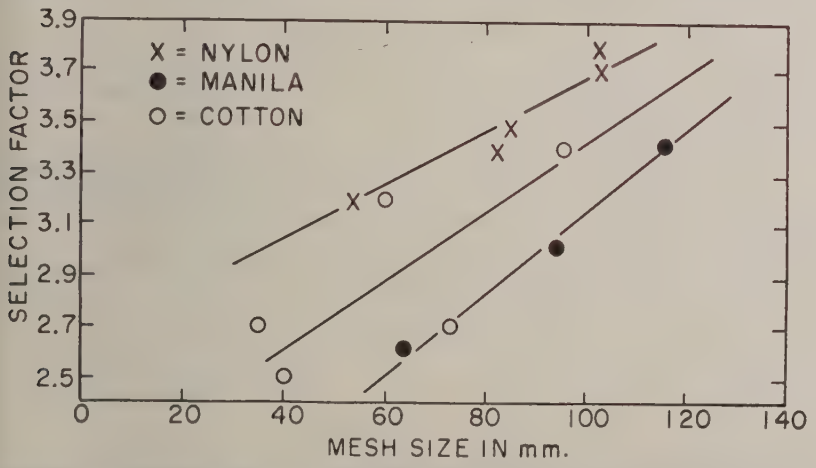

FIGURE 3.—Selection factor—mesh size relation for silver hake with nylon, manila, and cotton cod ends. Based on experiments conducted by North Atlantic Fishery Investigations.

cases. A non-linear relationship between the 50 per cent point and mesh size has been demonstrated for silver hake. This is shown in Figure 3 by the fact that the selection factor is not constant but changes with mesh size. Thus it cannot be accepted that the selection factor is constant over the range of mesh sizes for all species and the relationship must be considered separately for each case.

Research projects were recommended by the working parties of the Joint Meeting to provide solutions to specific problems. Some of this research is already yielding results. Certain studies with underwater television, for instance, which are underway at Woods Hole have provided valuable information on such things as: the action of cod end covers, the behavior of fish in the cod end at various towing speeds, the effect of additional layers of netting on top of the cod end (chafing gear), and the escapement patterns characteristic to various species.

The final test of the validity of selection experiments is, of course, the resulting effect upon the fishermen's catches. ICNAF, realizing the importance of testing the effect of its haddock regulation in this manner, required the maintenance of a licensed study fleet fishing with the small pre-regulation mesh nets as a control. Comparison of catches of this study group with boats using the regulation mesh confirmed the experimental results for haddock—both experimental results and study boat comparisons yielding a selection factor of 3.3.

Complex problems such as those arising from North Atlantic gear selection experiments, which are carried out by many nations, require close liaison between fishery researchers. The Joint Meeting of ICES, ICNAF and FAO by enabling workers from many nations to work together on their mutual problems, has provided a landmark in modern fishery research. Through close cooperation of researchers and the development of modern methods of research, such as underwater television, concepts are emerging to explain the puzzling variations in gear selection results.

LITERATURE CITED

Graham, Herbert W.

1952. Mesh regulation to increase the yield of the Georges Bank haddock fishery. ICNAF 2nd Annual Report, Part 3, pp. 23-33.

Permanent Commission

1956. Report of the *Ad Hoc* Committee established at the Fourth Meeting of the Permanent Commission September, 1955. Issued from the Office of the Commission, London, England, September, 1956. 38 pp.

Taylor, Clyde C.

1953. Nature of variability in trawl catches. U. S. Fish and Wildlife Service, Fishery Bulletin 83, Vol. 54, pp. 145-166.

(Reprinted from Annual Proceedings, Vol. 8, International Commission for the Northwest Atlantic Fisheries, pp. 101 to 102, 1958.)

V. Underwater Television Observations on the Effect of Chafing Gear on Escapement of Haddock

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The use of protective coverings or "chafing gear" over the upper surface of codends is a common practice in the ICNAF area. Chafing gear may be in the form of a second codend completely encompassing the primary codend or in the form of a piece of netting attached to the upper surface only. Hides or other material may occasionally be employed for chafing gear, but usually netting in some form is used.

The usual practice of fishermen is to affix the chafing gear very tightly to the codend, allowing little or no slack. This method allows no clearance between the two layers and the codend meshes are obstructed by the meshes of the overlying netting, resulting in reduced escapement of small fish from the codend. The degree of reduction will depend upon the dimensions and arrangement of the particular chafing gear. A reduction of 11 cm in 50 percent escapement point was reported by McCracken for typical Canadian chafing gear (reported to Scientific Advisers to Panel 4, December, 1956).

The Research and Statistics Committee recognized the possible detrimental effects of chafing gear in mesh regulation programs but concluded that the necessity of protection for codends justified its use. The Committee therefore recommended certain restrictions on the use of chafing gear to prevent obstruction of the codend meshes (see Ann. Proc. vol. 7, p. 13,). The Committee also recommended that further research be conducted on the effects of chafing gear, and the U. S. Fish and Wildlife Service undertook a study of the effect of chafing gear upon escapement of haddock with underwater television equipment.

The experiment was conducted 3½ miles west of Cape Cod on June 22, 1957, in 18 fathoms depth. A No. 41 Yankee trawl was towed at a speed of about 3½ knots by the 180 foot research trawler, *Albatross III*. The codend used was made of 127 mm mesh (ICNAF gauge measurement) double 50/4 manila twine and was 58 meshes around. The chafing gear was designed and attached in accordance with the recommendation of the Commission and consisted of a piece of netting, identical to that of the codend, 11 meshes in length and 44 meshes in width. As its lateral edges were fixed to the laceage of the codend it covered the upper half of the circumference of the codend (29 meshes) allowing the required 50 percent slack.

The escapement of haddock was viewed from both inside and outside the codend with the television camera being supported by a four-foot diameter iron frame. The arrangement for outside viewing is shown in Figure 1.

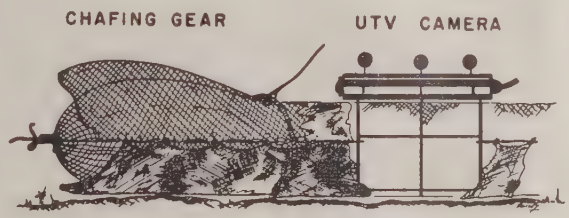

Fig. 1. Television camera rigged to study the effect of chafing gear on escapement from the codend.

Two successful tows were completed with the camera being positioned inside the codend on the first tow and outside the codend on the second. The abundance of haddock of the escape size was adequate, with about 400 fish of 30-50 cm length being taken per hour of towing. Natural illumination was adequate and no lights were used.

The codend under tow appeared to be distended with well-opened meshes. The mesh angle varied from 85° at the after end, where the codend reaches its maximum diameter, to 70° in the proximity of the camera.

The haddock which were observed inside the codend (Fig. 2) during the first tow displayed behaviour typical to those in codends without chafing gear observed under similar conditions. About 800 haddock (1,500 pounds) were taken in two hours of towing.

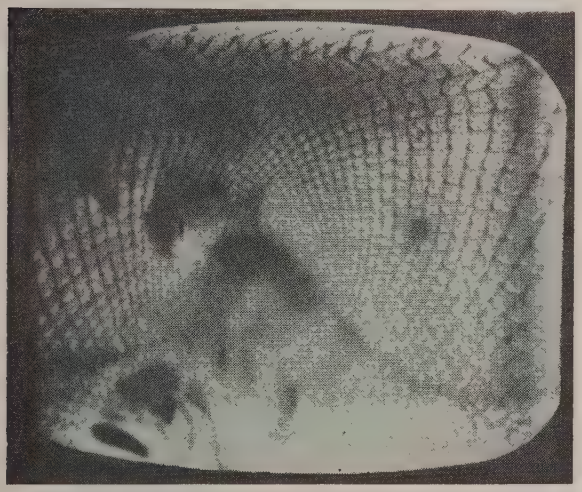

Fig. 2. Internal view of codend in action. The fish are haddock.

The camera was positioned atop the codend to permit better observation of the chafing gear and a second tow was made. The chafing gear was seen very clearly to flow up away from the codend, allowing about two feet clearance at its after end. The chafing gear meshes were not stretched so tautly nor extended so fully as those of the codend, however, and the whole piece of netting gave the appearance of being much slacker than the codend netting. Mesh angles varied from 90° at the after end to 60° at the forward end of the chafing gear.

All haddock attempting escape were successful and no fish became permanently meshed or otherwise lodged in the chafing gear. The escape patterns varied considerably.

Some fish avoided contact with the chafing gear entirely, passing down between the two layers of netting and escaping at the rear opening. Other fish swam straight upwards and escaped through the chafing gear meshes. Many fish became meshed and were able to escape only after a prolonged struggle. A few were seen to give up struggling with the mesh, back out of it, and swim out through the rear opening.

Our visual observations were supplemented by moving picture recordings of the television image. The frequency of the various chafing gear escape patterns as determined from analysis of a $3\frac{1}{2}$ minute film sequence is given below:

Total escaping	68
Number escaping through mesh:	
After considerable struggle	14
With no struggle	28
Number escaping through rear opening:	
After struggling with chafing gear mesh	4
Without contacting chafing gear	22

It may be concluded from these observations that chafing gear of the type approved by the Commission flows up clear of the codend under tow and does not obstruct the codend meshes nor interfere with the escapement of haddock through them. It may be further concluded that this type of chafing gear does not prevent haddock from completing their escape once they have emerged from the codend. Since fish escaped through the meshes as well as through the rearward opening of the chafing gear, it appears desirable to control both mesh size and degree of clearance. No conclusion can be reached from these observations as to whether sufficient clearance would be afforded by chafing gear having less than $1\frac{1}{2}$ times the number of meshes of the codend proper.

(Reprinted from Annual Proceedings, Vol. 8, International Commission for the Northwest Atlantic Fisheries, pp. 83 to 99)

III. Summary of Gear Selection Information for the Commission Area

By JOHN R. CLARK, FRANK D. McCRACKEN, and WILFRED TEMPLEMAN

INTRODUCTION

At the Joint Scientific Meeting of ICNAF, ICES (International Council for the Exploration of the Sea), and FAO (Food and Agriculture Organization of the United Nations) at Lisbon in 1957 working groups considered many aspects of our knowledge of gear selection. They reviewed the current status of knowledge and suggested further important research for each of these aspects. At the final session of this Joint Meeting it was concluded that many gear selection problems should be related to specific geographical areas and recommended that the status of gear selection knowledge in the ICNAF area should be examined in order to establish priorities for necessary gear research.

Two of the authors, Clark and McCracken, were asked to carry out this review and to report their results to the Research and Statistics Committee of ICNAF at the Eighth Annual Meeting. Templeman was subsequently asked for his assistance in preparing the redfish review.

We have taken as our basic terms of reference the species caught in the ICNAF area and the gears used to catch them. A limited amount of published data is available, but our sources of information are chiefly the papers presented at the Lisbon meeting (to be published by FAO). We have used primarily the results of gear selection experiments from the ICNAF area, but Northeastern Atlantic results were included where necessary.

We have considered only "inherent" (or intrinsic) selection by gear; that is, selective properties which can be modified by changing certain properties of the gear. We have not considered non-inherent (or extrinsic) selection, which results from such factors as non-representative distribution of fishing effort over the whole range of sizes of a stock of fish.

We are indebted to our colleagues on the Research and Statistics Committee of ICNAF for their helpful comments and suggestions on preparation of the manuscript. We are particularly grateful for the thoughtful and detailed criticisms rendered by Mr. Basil B. Parrish and Dr. Erik M. Poulsen.

SUMMARY OF SELECTION KNOWLEDGE

In order to present the summary of knowledge in the most concise manner possible we have reduced the text to a minimum of essential material. General background material concerning selection processes is included in Appendix I. Detailed derivations of the selection estimates are presented in Appendices II-VI.

Otter Trawls.

An extensive series of experiments with otter trawls has been carried out in the ICNAF area. The majority of the work has been concentrated on haddock, with lesser amounts of work on cod; redfish; American plaice, *Hippoglossoides platessoides* (Fab.); witch, *Glyptocephalus cynoglossus* (L.); and silver hake *Merluccius bilinearis* (Mitch.). Most of these results and results from a considerable amount of European work are available in the Lisbon papers and in other publications.

Escapement through forward parts of the trawl.

Replicate tow experiments with haddock in Subarea 5 have indicated in general that escapement through the lower wings and belly was substantial; but that escapement through top wings, square, and upper belly was relatively unimportant. The total numbers escaping from all forward parts of a trawl are lower, however, than for a codend of the same mesh size; the estimated 50% retention point for the No. 41 trawl, of $4\frac{3}{4}$ inch mesh (internal size), exclud-

ing the codend, occurred 5 to 12 cm lower than for a codend of equivalent mesh size. In addition escapement through the forward parts of the net may be of even lower practical importance, as many of the fish which may be prevented from escaping through forward parts of the trawl will escape through the codend.

Replicate tow experiments with an 84 mm mesh trawl have shown that the forward parts are important for the escapement of silver hake (Clark, 1957c). Most of the fish of less than 16 cm. escaped; about half of the fish of 16-33 cm escaped, with little selective action shown; and most of the fish above 33 cm were retained. No definite 50% escapement length can be chosen because of the extended range over which approximately half of the fish escaped. However, it can be concluded that the forward parts permit substantial escapement of sizes of fish which would have been at least partially retained if they had entered into a codend of the same mesh size. Controlling mesh size in the forward parts of the trawl thus appears more important for silver hake than for haddock.

The data are, however, insufficient to make quantitative estimates of haddock or silver hake escapement for different trawls and mesh sizes. No data are available with which to determine the importance of escapement from the forward parts of trawls for redfish, cod or plaice in the ICNAF area.

Escapement through the codend. In a trawl of uniform mesh size most fish of sizes within the selection range of the codend will escape from the codend rather than through forward parts of the trawl. The precise area of escapement will depend upon the amount of catch accumulating in the codend and the resulting blocking of the meshes. However, for moderate catches the greater escapement occurs in the after 6 or 8 feet. Most codend mesh sizes reported for selection experiments, however, represent averages for the whole codend, rather than the effective escape area only, and these are the figures which we have used.

The estimates of 50% retention lengths for various species in Tables 1 to 5 are based primarily upon experiments in the ICNAF area. The European data have been drawn upon where necessary, such as in the case of the variable haddock results for synthetics.

TABLE 1. Estimated 50% codend retention lengths for haddock taken by otter trawl. Selection span adjustment = 4 cm.

Mesh Size		50% Retention Length (cm)		
mm	in.	Double Manila Av. Selection Factor = 3.2	Single Cotton Av. Selection Factor = 3.6	Synthetics Av. Selection Factor = 3.5
102	4	32	35	35
108	4¼	34	38	37
114	4½	36	41	40
121	4¾	39	44	42
127	5	41	46	44
133	5¼	43	48	46
140	5½	46	52	48

TABLE 2. Estimated 50% codend retention lengths for redfish taken by double manila otter trawl codends. Selection span adjustment = 2 cm.

Mesh Size		50% Retention Length
mm	in.	Av. Selection Factor = 2.5
70	2¾	16
76	3	18
83	3¼	20
89	3½	22
95	3¾	23
102	4	25
108	4¼	27
114	4½	29

TABLE 3. Estimated 50% codend retention lengths for cod taken by otter trawl. Selection span adjustment = 5 cm.

Mesh Size		50% Retention Length (cm)		
mm	in.	Manila Av. Selection Factor = 3.5	Single Cotton Av. Selection Factor = 3.7*	Synthetics Av. Selection Factor = 3.8
102	4	36	38	39
114	4½	40	42	43
127	5	44	47	48
140	5½	49	52	53
162	6	53	—	61

*less reliable data

TABLE 4. Estimated 50% codend retention lengths for silver hake taken by otter trawl. Selection span adjustment = 4 cm.

Mesh Size		50% Retention Length (cm)		
mm	in.	Manila Single or Double	Cotton 72-84th	Nylon 400/3 Single
76	3	21	23	25
83	3¼	24	26	28
89	3½	26	29	31
95	3¾	29	32	34
102	4	32	35	38
108	4¼	36	39	41
114	4½	39	—	—

TABLE 5. Estimated 50% codend retention lengths for American plaice and witch taken by otter trawl. Selection span adjustment = 3 cm.

Mesh Size		50% Retention Length (cm)	
mm	in.	Manila Av. Selection Factor = 2.0	Synthetics Av. Selection Factor = 2.2
102	4	20	22
114	4½	23	25
127	5	25	28
140	5½	28	31

Estimates are presented for simplicity in the form of 50% retention lengths only. The range over which the selection operates is extremely variable. The reasons for such variations are not well known at present and cannot be discussed in a work of such restricted scope. Average figures have been determined and are provided along with the estimates of 50% retention lengths as selection span adjustments, which may be added to the 50% retention length to obtain the 75% point and subtracted to obtain the 25% point. The total range of codend selection can be taken as roughly twice the 25 to 75% span.

The derivation of our estimates is detailed in the appendices, where appropriate.

The relation between mesh size and the 50% retention length is linear for all species except silver hake for each type of material. The 50% retention lengths for haddock and redfish have been read from the regression lines shown in Appendices II and III. Because the lines have

appreciable intercept values, the selection factor (the ratio of fish length at 50% retention/mesh size) is not constant but varies with mesh size, but for convenience average selection factors have been estimated for the range of mesh sizes considered and are included with the tables.

Selection experiments for cod only extend over a fairly narrow range of mesh sizes, and in many cases cod have been taken as an incidental species. These data are insufficient to determine whether the selection factor is constant. The 50% retention length estimates in Table 3 are based on lines fitted to the 50% retention length and mesh size data shown in Appendix IV.

The 50% retention length/mesh size relation for silver hake is described better by a curve than a straight line (App. V). The escapement lengths have been estimated from the curve, and as average selection factors are not appropriate for this species, none have been provided.

Results for American plaice and witch suggest that selection factors for these species are similar to those for some of the flatfishes of European waters. The 50% retention lengths for these species, given in Table 5, have been determined in the same manner as for cod.

The Problem of Chafing Gear.

The codend results presented for all species are based upon single-layered codends which are uncovered on their supper surfaces. Various protective devices (chafing gear), such as secondary codends fitted over the primary codend or various covering materials, are commonly used in the ICNAF area. We have a little experimental evidence on the effect of such chafing gear on escapement. Such data as are available show that these protective devices may cause a substantial reduction in fish escapement with certain methods of application.

The considered opinion of ICNAF biologists is that a covering piece of netting should not markedly reduce escapement if affixed loosely and left open at its rearward edge. Whether this opinion is justified and whether chafing gears rigged in other ways could be used without reduction of escapement must await the results of further experiments.

Hook Selection.

Only a limited amount of information is available from which to judge the selective effect of various sizes and shapes of hooks. Little is known about the possible selective effect of various kinds and sizes of bait.

It has been established that hooks fished on longlines select sizes of fish from the stock generally in relation to the size of the hook, with large hooks catching fewer small cod than small hooks. Preliminary attempts to relate hook dimensions to sizes of cod caught appear promising, but as yet there is no well-defined relationship such as the selection factor for otter trawls. From the results available we are able to estimate selectivity values for some hooks currently in use.

Data for handlines are insufficient for reliable estimates but generally indicate that handline selective action may not be so directly related to hook size as that of longlines. The catch of the smaller sizes of cod and haddock, i.e., those within the selection range of $4\frac{1}{2}$ inch mesh codend, is low in the ICNAF area for both methods of hook fishing.

Cod. Some results for hooks fished on longlines are available for the ICNAF area (McCracken 1957a) and off Norway (Saetersdal 1957c). The estimates of selection provided by these experiments are given in Table 6.

TABLE 6. Cod selection estimates for hooks fished on longline.

Hook Type	50% Escapement Length	25-75% Selection Span
No. 17 Mustad	ca. 35-40 cm	?
No. 14 Mustad	48	12-14 cm
No. 7 (Norwegian)	55	14 cm
No. 11 Mustad	65	15-18 cm

For handlines we can only say (1) that results of Saetersdal's experiments suggest similar selectivity for handlines and longlines, and (2) that size composition of cod catches off the Newfoundland east coast suggests that large handline hooks catch the same size cod as smaller longline hooks.

Haddock. Limited results obtained by McCracken (1957a) for longlines provide the only information available for haddock. These results indicate that hooks select sizes of haddock in a manner similar to otter trawls. McCracken's data are too limited to predict a 50% retention

length and indicate only that the smallest hook used by Canadian longliners (No. 17) appears to release as many haddock as a 4½ inch mesh codend. Nothing is known about handlines election.

Pair Trawls.

There are no data on selection by pair trawls. They are so different in design and operation from otter trawls that we have not considered inference of their selection properties from those of otter trawls to be valid. Pair trawls used in the ICNAF area are made of natural fibres (manila or sisal). The twine used in these nets is usually light and flexible, the codends are unprotected on top, and their mesh size is larger than that of the otter trawls. Moreover, it is believed that pair trawls fish higher in the water than the conventional otter trawl. Comparable observations on length composition of catches by pair trawls and otter trawls are not available.

Gill Nets.

No data are available on the selection of groundfish by gill nets in the ICNAF area.

Traps.

No experimental evidence is available with which to make estimates of the selection by traps. Some general knowledge of the use of traps and their catches is presented in Table 7.

Danish Seines.

European experiments have shown that seine net escapement is usually higher than otter trawl escapement for equivalent mesh sizes. Since Danish seining is of little importance in the ICNAF area and species caught differ from those caught in European waters, no estimates have been attempted from the European information.

FURTHER RESEARCH REQUIREMENTS

Any evaluation of the adequacy of our current knowledge of gear selection must be related to the importance of species and gears. To this end we have presented in Table 8 a summary of landings from the ICNAF area for 1955. The most important species is cod; followed by haddock; redfish; and flounders, of which the American plaice is the leading species. The relative importance of species varies somewhat from subarea to subarea.

TABLE 7. Information regarding catches and selectivity of traps.

Species	Where Traps Used	Sizes Caught	Selection
Cod	Extensively for inshore fisheries of Subareas 2 and 3 and Subdivisions 4R and 4S. Also used in Subarea 1.	For example, off Nfld. east coast 1950-53, 14% by number under 45 cm; 54% by number under 55 cm.	About 15-20% by number within selection range of 4½″ mesh; more than 50% within selection range of 5½″ mesh. However, since traps take the smallest fish in the area, there is no quantitative evidence re possible escapement.
Haddock	Small catches in Subarea 4.	Vary: in 1928 less than 2% under 45 cm, 30% under 55 cm in 1955—none of scrod size (under 50 cm)	Catches mainly large haddock. General knowledge of the area suggests only large fish present; thus scarcity of small fish in the catch not a result of escapement.

TABLE 8. Statistics of landings from the ICNAF area, 1955, in thousands of metric tons.

Species	SUBAREA 1	2	3	4	5	Total
Cod	265	26	429	159	12	892
Haddock	—	—	105	43	51	198
Redfish	32	—	18	60	14	123
American Plaice	—	—	15	12	2	} 60
Witch	—	—	3	7	1	
Other Flounders	1	—	1	2	16	
Halibut	1.4	—	1	1.8	—	4
Pollock	—	—	7	19	10	36
Silver Hake	—	—	—	—	46	46
Other	4	—	2	17	107[a]	130

[a] Includes menhaden, herring, alewives, etc.

TABLE 9. Landings of major species by different gears from the ICNAF area, 1955, in thousands of metric tons.

Gear	Cod	Haddock	Redfish	Flounders
Otter trawls				
over 500 tons	345	56	32	—
151-500 tons	28	77	91[a]	56[a]
under 151 tons	30	48		
Pair Trawls	33	4	—	—
Traps	ca. 100+	Some	—	—
Hooks (Longline and Handline)	ca. 300+	ca. 12	—	0.3
Seine Nets	Negligible	Very few	Very few	1.3
Gill Nets	Negligible	Few	—	—

[a] Categories "151-500 tons" and "under 151 tons" combined.

Summaries of the catches by various gears are given in Tables 9 and 10. Otter trawls are of the greatest overall importance for cod, particularly those of trawlers over 500 tons. However, hooks and traps are also of considerable importance, especially in the inshore fishery. For the remaining species, otter trawls, primarily those of trawlers under 500 tons, are most important.

TABLE 10. Landings of minor species by different gears, from the ICNAF area 1955, in thousands of metric tons.

Gear	Halibut	Pollock	Silver Hake
Otter Trawls	0.8	Some pollock caught by most gears in Subareas 3, 4, and 5.	46
Hooks	1.7		—
Miscellaneous	1.7[a]		—

[a] Mainly hooks

We are lacking information on the catches of many important species by certain gears. The best summary of research needs in gear selection is given in the "Outline of Present Research and Long-Range Needs in the Convention Area" prepared by the Research and Statistics Committee in 1956. Although some progress towards filling the indicated gaps in our knowledge has been made since preparation of this document, it still summarizes current essential needs in gear selection research. The following excerpt contains the two sections relating directly to gear selection:

"(1) Determination of the size selectivity of different kinds and sizes of fishing gear.

Present Status: Selectivity of the catching gear is unknown for about 80% of the cod taken in the area. More adequate knowledge is available for about 75% of the present haddock catch.

a. Otter trawl selectivity—Much research has been carried out with single, large mesh codends by several countries. Selection experiments with multiple codends have not been attempted.

b. Pair trawl selectivity—Inactive.

c. Hook selectivity—Canada has compared the selectivity of various sizes of hooks. Norway has compared the sizes of fish caught by hooks with the sizes of fish caught by other gears.

d. Trap selectivity—Inactive.

Additional Resources Required:

a. Mesh experiments with traps should be carried out by countries using these gears to determine what effect mesh size has on the size of the fish caught.

b. Selective properties of otter trawls with multiple cod ends should be obtained by the countries using these gears. Covered net experiments and comparative fishing experiments are recommended.

c. Present knowledge about hook selection should be assembled and considered in relation to mesh selection. This would provide a basis for planning further hook selection experiments.

d. Length composition samples of cod and haddock taken by different gears should be compared to help assess the general problem of selectivity. For each sample a complete description of the catching gear must be included.

(2) Determine which parts of the trawl and which sections of the codend contribute most significantly to the release of fish. Determine what factors cause variation in mesh selectivity, such as effect of catch size, towing time, towing speed, differences between material, etc.

Present Status: In the ICNAF area a number of mesh selection experiments have been carried out by Canada and the U.S. Experiments are continuing on the differences in selection for different materials. Many of the experiments carried on by other countries outside the ICNAF are are applicable.

Additional Resources Required:

Most of the mesh selection experiments carried out in the ICNAF area have been only summarily analyzed. All extant mesh selection data should be analyzed with emphasis given to determining the causes for variation in selection results and amount of escapement in forward parts of the trawl. Results of the analysis should be presented as a basis for determining what further mesh selection experiments are needed. Because future planning is so dependent on the consideration of these past experiments, this should be carried out as soon as possible. Publication of the results by ICNAF should be considered."

Good progress has already been made in carrying out the goals of (2) above. This was accomplished through the workshop gathering of American and European gear selection workers at the Joint Meeting of ICNAF, ICES, and FAO in Lisbon during May and June of 1957. The collection of experimental results presented at the meeting is scheduled for publication in 1959.

APPENDIX I: GENERAL BACKGROUND MATERIAL

How Gear Selectivity is Measured.

The selectivity of gear is determined usually by either capturing the fish which have escaped the gear (covered codend experiments) and comparing their sizes with those retained by the gear, or comparing the catches of different gears fished at the same time and place. These comparisons usually reveal at first a slow increase in the retention of fish from the smallest size at which some are first retained, followed by a rapid increase in retention, and finally reaching a stage of only gradually increasing retention to the point where full retention is achieved. When such data are plotted they take the form of an extended "S-shaped" or sigmoid curve, the "selection curve" for the gear. A typical selection curve is shown in Figure 1.

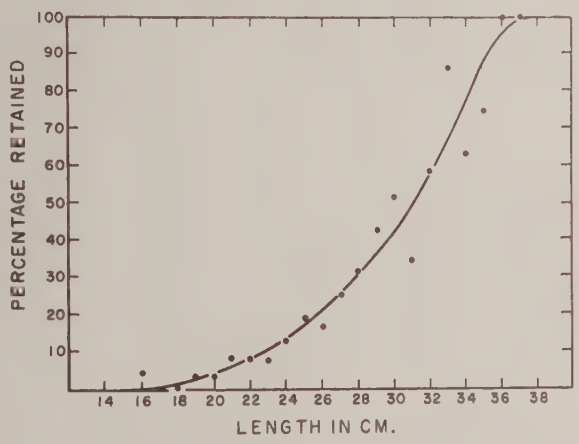

Fig. 1. Percentage of redfish of each length retained by a manila codend of 132 mm mesh size. (From data of Clark 1957e).

Variations from the S-shaped pattern are found for certain gears such as gill nets, in which the retention increases to its highest value at a certain fish size and then decreases again past that size, thus describing a bell-shaped or normal curve.

How the Selectivity Process is Defined.

Selection of the type that takes place in otter trawls is defined by various properties of the sigmoid selection curve. These properties are usually the lengths of fish retained at various points along the curve, such as the 25, 50, and 75% retention points. Selectivities of different gears and sizes of gears are most often described simply by giving their 50% retention lengths (the length at which 50% of the fish are retained by the gear and 50% escape). The selection

span (distance between 25 and 75% retention lengths) is often included to give a measure of the steepness of the curve. The "regression coefficients" are often used to describe the relation between 50% retention length point for various gears and average internal size of mesh (see Appendix III for illustration). If the form of this relation has an intercept of 0, the "b" value of the regression formula is sufficient to define the relation. This value, termed the "selection factor," is thus the quotient of 50% retention length/mesh size, a higher factor indicating greater escapement (Permanent Commission, 1956). Selection factors for otter trawls, for example, will vary from 2.0 to 5.0, depending principally upon the species and material from which the netting is made.

The Range of Fish Sizes over which a Selection Process Extends.

The selection process is not precise, but as shown in Figure 1 operates over a more or less extended range of fish sizes. For otter trawlers it has been found experimentally that meshes over 150 mm select sizes of haddock over a range of 35 cm or more. This range, called the selection range, which extends from zero to one hundred percent retention has been related to the size of the mesh. The range is very much smaller for smaller sizes of mesh; for instance, reduced to about 8 cm for a mesh of 75 mm for haddock.

Difficulties Arising from the Extended Selection Range.

Although the gear operates selectively over a large range of sizes, the greatest selection occurs within a much narrower range of sizes. Most investigators consider the important part of the selection range as that occurring within the "selection span". The haddock selection span, for instance, may be as small as 4 cm in 75 mm meshes and as great as 14 cm in meshes of 150 mm or over. This means that to obtain substantial escapement of a certain size of fish one must accept the escapement of a substantial quantity of fish over those sizes. For example, if one is to obtain 75% encapement of 34 cm haddock from a trawl net, one must allow about 60% escapement of the fish at 36 cm, 40% at 38 cm, 25% at 41 cm, and smaller percentages of the larger sizes. This factor must be taken into consideration in recommending mesh sizes for fisheries to be sure that proper allowances are made.

Effect of Experimental Error.

The variations in gear selection results arise from experimental and from substantive causes. As an example of the kind of experimental error encountered, the use of a small mesh cover over the codend may easily result in a dampening of the escapement if the cover is not properly fitted. Results from replicate tows with large and small mesh nets tend to give higher escapement values than those from covered codends, as observed by Saetersdal (1957a) and Clark (1957g). This presumably comes about through differences in the catching rate of the two gears for different sizes of fish which are not due to the actual selectivity of the meshes. The greatest problem in comparing results of various experiments is that of isolating the causes of variation and attempting to find reasons therefore.

Selective Properties of the Trawl for Different Species.

Marked differences in escapement values have been shown for various species, although the reasons for this are not well understood. The relation between fish shape and mesh shape is undoubtedly important. Flatfish, for example, do not escape nearly so well in respect to their length as roundfish. This could be expected because they are so much broader. Redfish, which have a relatively low girth factor (length/girth ratio) compared to other roundfish are also characterized by low escapement in respect to length. Also there may be important differences among various species of the same family. Cod, for example, escape in somewhat greater numbers at any size than haddock. Silver hake which should, because of their high girth factor, escape in greater numbers than haddock, actually do not. This means that selection has to be determined separately for each species.

Escapement of Fish from Forward Parts of the Net.

It has been accepted that most of the escapement from otter trawls takes place in the codend. However, recent data indicate that although this is true in general, appreciable numbers of some species escape through the forward parts of the net. This escapement is usually restricted to smaller sizes of fish than escapement through the codend.

Data from experiments in the ICNAF area have shown, for instance, that nearly 100% of the very smallest sizes of haddock and silver hake escape through the forward parts of the net (Clark 1957c). A considerable, but gradually reducing, amount of escapement takes place toward the larger sizes in normal sigmoid fashion. In relation to the area of netting available, however, escapement through the forward parts is quite low as these parts contain 50 to 100 times as many meshes as the codend. Furthermore, for haddock the 50% point occurs at a lower fish size for the forward netting than for the codend, with the same mesh size in each.

It has been demonstrated that fish do not escape equally throughout various parts of the codend, but rather escape through the first few rows of clear meshes ahead of the accumulated catch (Beverton, 1957b; and Clark 1957b).

Differences in Escapement Associated with Differences in Net Material.

The most important substantive (non-experimental) sources of variation in selection work are those associated with the type of material of the nets. At equivalent mesh sizes, meshes of lighter, more flexible twines usually give higher escapement than those of heavier and stiffer twines. For example, the 50% retention length for haddock is about 5 cm higher for a single cotton than for a double manila codend at a mesh size of $4\frac{1}{2}$ inches (Table 3). Similarly, for silver hake it has been shown to be about 6 cm higher for light single nylon than for single manila at a mesh size of 4 inches (Table 5).

Effect Upon Escapement of the Speed with which the Net is Towed.

Little direct evidence is available on this subject because few controlled experiments on the effect of different towing speeds on escapement have been conducted in the ICNAF area. However, some of the differences in escapement between large boats and small boats (which tow more slowly) are probably due to differences in towing speed. Experimental trawling for selection purposes is usually carried out at a towing speed approximating commercial practice so that results will be directly applicable. However, "commercial practice" varies from fishery to fishery and area to area, making it difficult at times to compare and utilize the results of various experiments.

Effect Upon Escapement of the Length of Time During which the Net is Towed.

That longer tows appear to afford greater escapement has been documented for the ICNAF area in controlled haddock escapement experiments in which the 50% retention length increased by more than 5 cm in one series of tows when towing time was increased from 20 to 80 minutes (Clark 1957a).

European work has not altogether confirmed this, although there is some suggestion in Gulland's (1956) results that 3 hour tows may give higher escapement than $1\frac{1}{2}$ hour tows. No difference is apparent in the results of Parrish and Pope (1957).

Such differences as may be found will not be so large as to interfere greatly with comparison of experimental results or with their application, since tows usually approximate commercial practice, which is most often 60 to 120 minutes in the ICNAF area. The difference in 50% retention lengths between these extremes should be only a centimeter or two.

Size of Catch in Relation to Escapement from Codends.

Many investigators have shown that larger catches are generally associated with lower escapement. Work in the ICNAF area has

shown that the codend 50% point for haddock, for example, may decrease 5 cm from light to heavy catches. The expected catch level in a fishery should thus be considered in planning mesh control programs.

Escapement from the Trawl Net Under Tow.

It has been amply demonstrated that meshes of the net remain open during towing and that fish escape during this time, not just while the net is being hauled. Davis (1934), for instance, demonstrated with a special choking device on the codend cover that 90% of the fish escaped while the net was under tow. Davis's findings have subsequently been confirmed by observations of SCUBA divers in shallow water and underwater television in deeper water.

Whether the fish escape undamaged or suffer injuries, perhaps, mortal, in escapement has not been adequately answered. Examination of limited results from tagging of escapees taken in codends and covers has not indicated any greater mortality for those which passed through the codend meshes into the cover. The SCUBA and underwater television observations have shown fish to swim away very vigorously, and apparently unhurt, after escaping from codends under tow. It is, of course, possible that the escape effort could result in damage having some later consequence.

Experimental Results Compared with the Results of Large Mesh in Practice.

Davis (1934) compared catches with large and small mesh on two commercial trawlers and demonstrated that selection experiments were borne out in practice. Clark's study of the regulated Georges Bank fishery has shown selectivity of the $4\frac{1}{2}$ mesh for haddock to be almost exactly that predicted by the experimental evidence.

Increased Efficiency of Large Mesh Otter Trawls.

It is a common result in comparison of catches of large and small mesh gears to find that larger meshes catch more fish of the larger sizes. This was first shown by Davis (1934) who showed that the large mesh caught 11% more fish of sizes beyond the selection range. Perhaps the best demonstration is that for the Georges Bank haddock fishery, in which the regulated ($4\frac{1}{2}$ inch mesh) trawlers caught 9% more fish of larger sizes than the small mesh ($2\frac{7}{8}$ inch) study group vessels (Clark and Nichy 1957). These increases are noticeable particularly for sizes of fish just beyond the selection range of the net.

The Value of Special Trawl Gears Devised for Improving Escapement.

Various types of special trawls or modifications of trawls have been devised with the hope of improving the precision of the selective action of the net. These trawls, incorporating rigid meshes of wire, special "escapement panels", or meshes hung in a special fashion to insure their being open, have not shown sufficient superiority over the standard type of netting to be considered for introduction into the fisheries.

APPENDIX II: HADDOCK SELECTION

So much data are available from codend selection trials with haddock that time did not permit an exhaustive analysis of the causes of variation. The lines of best fit plotted in Figures 2 to 5 were calculated by the least squares method from 50% escapement lengths for various mesh sizes. In Figure 3, the data of "early U. S. trials" were those of Herrington (1935). "Early European trials" were those reported by Bowman (1928), Davis (1934), Russell and Edser (1926), and Todd (1911). The data of Parrish are partly from the Lisbon papers (with Pope 1957) and partly from personal communication. "Other recent European trials" consist of data from the Lisbon papers of Beverton (1957a), Margetts (1957), Saetersdal (1957b), and v. Brandt (1957). The data shown in Figures 2, 4, and 5 are from the Lisbon papers of Clark (1957d), Margetts, McCracken (1957c), and Templeman (1957a). The category "European" in Figure 5 includes the data of Margetts and v. Brandt.

The line for manila (Figure 2) was fitted to the results of 30 separate trials. Only those results for 45/4 and 50/4 twine were used in the

least square calculation as these are the common sizes in use in the ICNAF area. Inclusion of results for 75 and 125 yard twines would affect the line very slightly, however. The European and early U.S. experiments are included in Figure 3 for comparison. The European experiments vary considerably but in general confirm the ICNAF line. The early U.S. experiments, based on alternate tows and "trouser" codend methods, are now not considered to be applicable because of the difficulty of translating Herrington's mesh measurements into those presently used and because of the inherent bias in the experimental methods used.

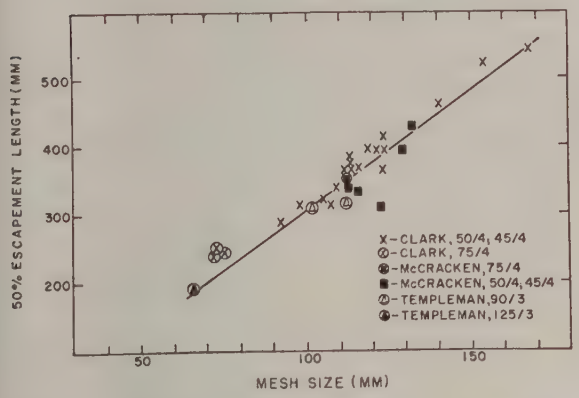

Fig. 2. **Haddock 50% retention lengths for double manila for the ICNAF area. Line fitted to 45/4 and 50/4 data only.**

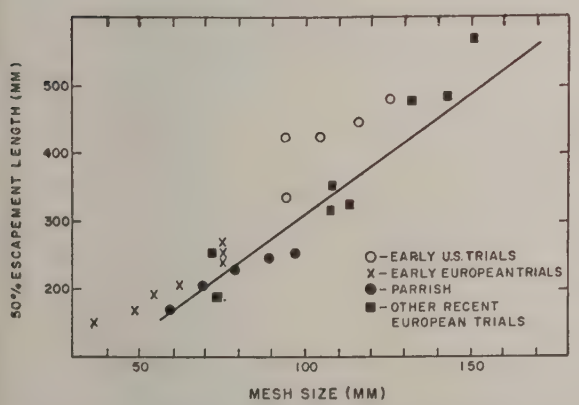

Fig. 3. **Haddock 50% retention lengths for double manila for the European area, with the ICNAF line (from Fig. 4) drawn in for comparison.**

The line for manila, when extrapolated, does not pass through the zero point. For this reason the selection factor is not constant, but an average factor of 3.2 is roughly applicable to the middle range of values and will suffice for most purposes. Nor does the line of best fit for single cotton (Figure 4) pass near the intercept. The one European point (not included) would have the effect of drawing the intercept somewhat nearer to zero.

The data for synthetics are much more variable (Figure 5). All the synthetics are considered together since so few data are available for the individual types. Final consideration of

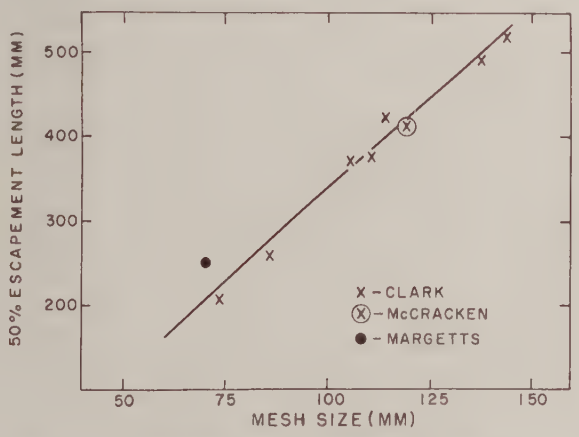

Fig. 4. **Haddock 50% retention lengths for single cotton.**

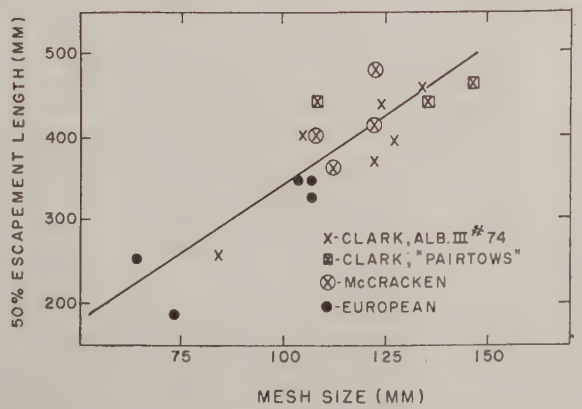

Fig. 5. **Haddock 50% retention lengths for all synthetics.**

differences in various kinds of twine must await more detailed analysis. One factor of considerable importance is that synthetic codends often have much larger meshes at their after ends, past the splitting strap, due to the stretching effect of the weight of fish being hauled aboard. This will produce an effect of higher 50% retention lengths for given average mesh size of the whole codend, since most fish escape from the area behind the splitting strap. If the 50% length is plotted against the mesh size in the after quarter only, for the U. S. experiments a somewhat better fit is obtained. For the purpose of making our estimates we have fitted the line in Figure 5 to all data on the basis of the average mesh size for the whole codend.

APPENDIX III: REDFISH SELECTION

The data used for the following analysis have been taken mainly from the Lisbon papers of Clark (1957e), McCracken (1957b), Saetersdal (1957b), and Templeman (1957b). All the data except those of Saetersdal are for the American form of redfish tentatively referred to as *Sebastes marinus mentella.* Saetersdal's selection data are for *Sebastes marinus marinus.* Saetersdal's mesh sizes were measured under 8 lb. pressure, while the remainder of the mesh size data are for 12 lb. pressure. In all cases the codend meshes were of double manila twine. All the redfish measurements were from the chin, with the mouth closed, to the end of the median ray of the caudal fin.

All the alternate tow data have been adjusted by assuming that large redfish, those beyond the size of 100% retention by the codend meshes, were present in good numbers in both large and small meshed nets and by adjusting the remaining part of the frequency accordingly.

In the alternate tow work the large mesh nets had codend, lengthening piece, and after belly meshes of the large mesh, while the remaining forward parts were of the same mesh size as forward parts of the small mesh nets (usually 6 inch mesh overall, apart from the usual gradation of mesh sizes from the forward belly to the size used in the after part of the belly).

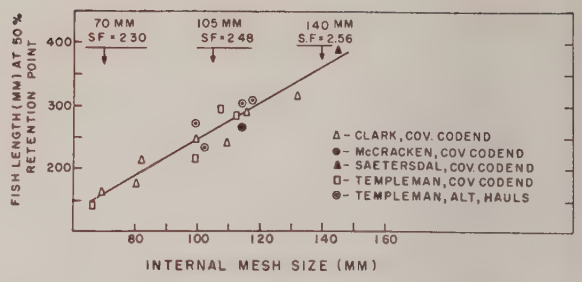

Fig. 6. Redfish 50% retention lengths for double manila codends, 45/4 - 125/3.

Figure 6 indicates that the selection factor for redfish increases with mesh size; e.g. from 2.30 at a mesh size of 70 mm to 2.56 at a mesh size of 140 mm. The factor for 75% retention also increases with mesh size, from 2.54 at a mesh size of 70 mm to 2.75 at a mesh size of 140 mm (Figure 7) as would be expected.

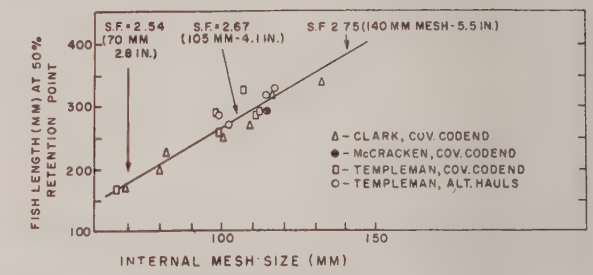

Fig. 7. Redfish 75% retention lengths for double manila codends, 45/4 - 125/3.

Figure 8 shows that the escapement for 45-50/4 manila, for which data are available only at the larger mesh sizes, is usually lower than that for 90-100/3 manila. It is thus possible that if heavier twine had been used at smaller mesh sizes the selection factor would have declined even more rapidly.

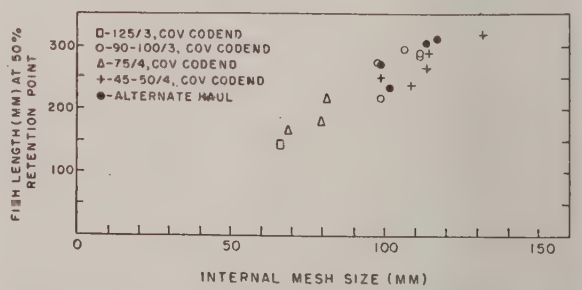

Fig. 8. Redfish 50% retention lengths for double manila codends of different twine sizes.

The data of Clark and Templeman have been further analyzed to show that in the covered codend experiments (Figure 6), the selection factor is lower with larger catches and higher with smaller catches.

Most of the selection points in the figures were obtained from experiments in which there were small to moderate catches. Selection factors are needed for larger hauls, preferably from the paired tow method, or if this is not possible, from alternate tows by commercial vessels with different mesh sizes operating in areas where large catches are obtained.

APPENDIX IV: COD SELECTION

Within the ICNAF area cod are caught in quantity by the greatest variety of gears, which include otter trawls, hooks, traps and pair trawls.

Results of selection experiments with hooks of different sizes have been taken from McCracken (1957a). Comparisons of sizes of cod caught by longline and otter trawl have been derived from McCracken (1957a) and Saetersdal (1957c). Comparisons of sizes of cod caught by handlines and traps have been taken from Templeman and Fleming (1956).

In many cases the otter trawl selection results for cod have been a by-product of selection experiments for haddock. Data are available only for a fairly narrow range of mesh sizes and experiments have not been carried out with small mesh codends.

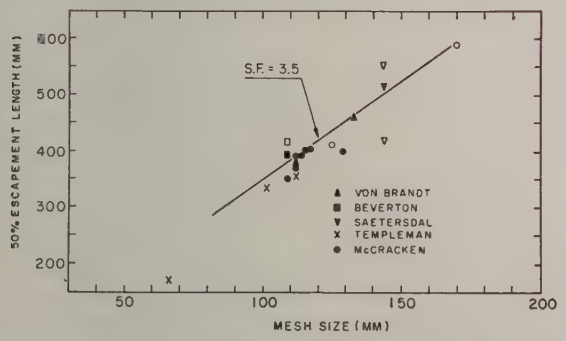

Fig. 9. **Cod 50% retention lengths for manila codends of double strand construction. Open symbols represent results from experiments with less than 50 fish per tow in the selection range.**

Results of covered net experiments with manila codends show a selection factor of about 3.5 for cod, Figure 9. A comparison of the length composition of cod caught by large and small mesh manila nets in the commercial fishery of Subarea 4, suggests a similar selection factor. Results of covered net experiments with nylon and perlon codends show a selection factor of about 3.8 for these materials, Figure 10. Selection experiments for cod with cotton codends have included only two mesh sizes (102 and 119 mm). These experiments suggest that cotton has a selection factor of about 3.7, intermediate to that of manila and synthetics.

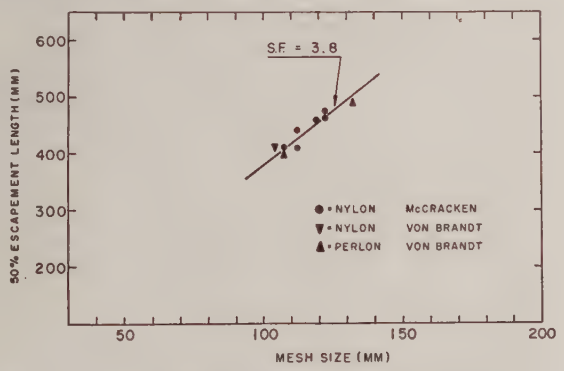

Fig. 10. **Cod 50% retention lengths for nylon codends of both double and single strand construction and perlon codends of double strand construction.**

The selection span, as described by the distance between 25 and 75 percent retention lengths is quite variable, Table I. Results for manila codends indicate that selection span increases with mesh size. The selection span for manila codends also appears to be greater than for nylon codends of similar mesh size. For purposes of this report a selection span of 10 cm has been chosen as most representative.

TABLE I. Selection spans for cod in covered net experiments with manila, nylon and cotton codends.

Selection Span	Codend Material and Frequency		
cm	Manila	Nylon	Cotton
6	2	3	—
7	1	1	—
8	2	1	2
9	2	—	—
10	6	—	—
11	2	—	—
12	3	—	—
TOTAL	18	5	2

APPENDIX V: SILVER HAKE SELECTION

The only extensive codend selection trials for the ICNAF area were conducted aboard a small (47 gross tons) otter trawler, *Priscilla V.*, of the type which carries out the major part of the silver hake fishery (Clark 1957f). The trawler towed a small net slowly ($2\frac{1}{2}$ knots) and results may not be directly applicable to larger trawlers. Examination of these data (Figure 11) indicated much duller and much lower escapement than would be expected from the girth of silver hake.

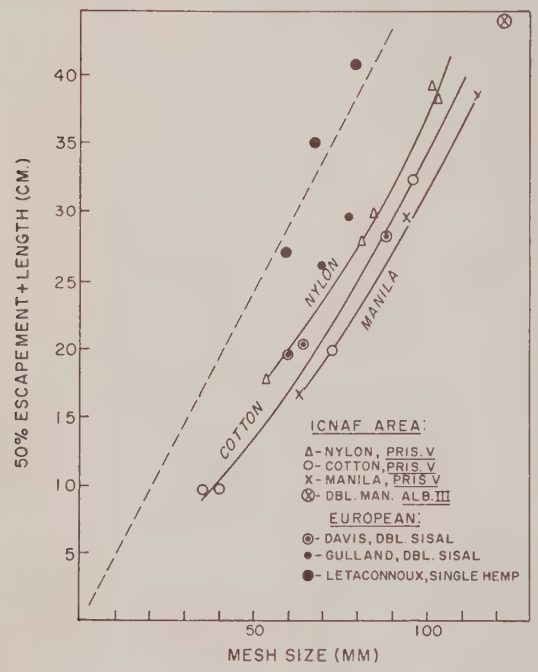

Fig. 11. **Silver hake 50% retention lengths and mesh size. The dashed line represents mesh circumference = fish girth (for *M. bilinearis*).**

Higher escapement is indicated by experiments on the related European hake. The relation between mesh size and 50% escapement length is fitted better with a curve than a straight line. The curves for the three different materials are of analogous shapes. The line for cotton may be extrapolated back to the zero point. It is perhaps reasonable to assume that the other two curves might also be fitted to conform to a zero intercept. However, consideration of the significance of intercepts is beyond the scope of this study and the estimates of 50% retention lengths have been interpolated from the curves shown which have been fitted as closely as possible to the data for each material.

The single point for double manila (*Albatross III*) was not used in drawing the line as a specific 50% point could not be estimated from the sparse data. These data do, however, indicate a 50% retention length of a minimum of 450 mm for the 123 mm mesh, which is somewhat higher than would be indicated from the *Priscilla V.* work. More selection trials must be carried out with the heavier gear and faster towing speeds of larger trawlers to ascertain whether, in fact, they would provide greater escapement.

European data, as summarized by Gulland (1956) and giving higher selection, are indicated in Figure 11. The data of Davis (1934) coincide well with the ICNAF data. Gulland's own data give higher, but not unreasonable, estimates.

The data of Letaconnoux (1955) are so much higher, notwithstanding the fact that they are for single twine of hemp, as to be considered inappropriate for our use. These data are for replicate tows which seem usually to yield higher escapement estimates than those for covered codends. The data of Letacconoux show half the hake escaping of a size which, on the basis of data for silver hake in the ICNAF area, are larger in girth than the mesh is in circumference and theoretically would be too large to pass through the meshes (see dashed line in Figure 9). Moreover, this is only the 50% length, indicating that many even larger fish are escaping. Notwithstanding the fact that the mesh size is only an average and some larger meshes are undoubtedly present, such escapement estimates remain extraordinarily high and more intensive examination of Letaconnoux's data would be required before they could be considered appropriate for our purposes. As such extensive analysis is beyond the scope of this report, the European data have not been utilized for our estimates.

APPENDIX VI: FLATFISH SELECTION

Otter trawl mesh selection results for two species of flatfish, American plaice and witch, are presented in Table 5, p. 86. These data have been obtained as by-products of selection experiments for various roundfish species. The data for American plaice are presumably better than those for witch, since they were caught in larger numbers.

These results suggest a selection factor for American plaice of about 2.0 with manila codends and 2.2 with nylon codends. It is probable that the selection factors for witch are slightly higher than for American plaice. Selection factors of the above order are similar to those found for the European plaice from extensive experiments carried out in the North Sea.

Literature Cited

Beverton, R. J. H. 1957a. Mesh selection of cod (North Sea and Arctic) and haddock (Arctic). Paper presented at Joint Meeting of ICNAF, ICES, and FAO. Lisbon, 1957.

Beverton, R. J. H. 1957b. Escape of fish through different parts of a codend. Ibid.

Bowman, A. 1928. The qualitative effect of different fishing gears on the stock of the marketable species. Cons. Perm. Internat. Explor. Mer., Rapp. Proc.-Verb., vol. 52, pp. 227-238.

vonBrandt, A. 1957. Selectivity data for synthetic fibres. Paper presented at Joint Meeting of ICNAF, ICES, and FAO. Lisbon, 1957.

Clark, John R. 1957a. Effect of length of haul on codend escapement. Paper presented at Joint Meeting of ICNAF, ICES, and FAO. Lisbon, 1957.

Clark, John R. 1957b. Effective escape area of the codend. Ibid.

Clark, John R. 1957c. Escape of fish through various parts of the trawl. Ibid.

Clark, John R. 1957d. Escapement of haddock through codends. Summary of United States experiments. Ibid.

Clark, John R. 1957e. Escapement of redfish through codends. Summary of United States experiments. Ibid.

Clark, John R. 1957f. Escapement of silver hake through codends. Summary of United States experiments. Ibid.

Clark, John R. 1957g. Validity of the covered codend method. Ibid.

Clark, John R. 1958. Underwater television observations of the effect of chafing gear on escapement of haddock. ICNAF Ann. Proc. for the year 1957-58, vol. 8.

Clark, John R. and Fred E. Nichy. 1957. Fishing efficiency of regulated Georges Bank trawlers. Paper presented at Joint Meeting of ICNAF, ICES, and FAO. Lisbon, 1957.

Davis, F. M. 1934. Mesh experiments with trawls, 1928-1933. Ministry Agric. and Fish., Fish. Invest., Ser. II, vol. 14, No. 1, 56 pp.

Gulland, J. A. 1956. On the selection of hake and whiting by the mesh of trawls. Jour. Cons., Cons. Perm. Internat. Explor. Mer., vol. 21, No. 3, pp. 296-309.

Herrington, William C. 1935. Modifications in gear to curtail the destruction of undersized fish in otter trawling. Bureau of Fisheries, U. S. Dept. of Commerce, Investigational Report No. 24, 48 pp.

Letaconnoux, R. 1955. Expérience de pêche avec des chaluts de dix-huit mètres a maillage différénts. Rev. Trav. Inst. Pêches Marit., vol. 19, No. 1.

Margetts, A. R. 1957. A mesh experiment with sisal, cotton and nylon codends. Paper presented at Joint Meeting of ICNAF, ICES, and FAO. Lisbon, 1957.

McCracken, F. D. 1957a. Hook selection for cod and haddock. Ibid.

McCracken, F. D. 1957b. Selection by large mesh codends of flatfish and redfish. Ibid.

McCracken, F. D. 1957c. Selection factors for cod and haddock with codends of different materials. Ibid.

Parrish, B. B. and J. A. Pope. 1957. Further results on the effects of using small-mesh covers: Effects on the catches of the escape sizes of fish. Ibid.

Permanent Commission. 1956. Report of the Ad Hoc Committee established at the Fourth Meeting of the Permanent Commission September, 1955. Issued from the Office of the Commission, London, September, 1956.

Russell, E. S. and T. Edser. 1926. The relation between codend mesh and size of fish caught. Preliminary experiments with the trouser trawl. Jour. Cons., Cons. Perm. Internat. Explor. Mer., vol. 1, No. 1, pp. 39-54.

Saetersdal, G. 1957a. A note on the methods used in mesh selection experiments. Paper presented at Joint Meeting of ICNAF, ICES, and FAO. Lisbon, 1957.

Saetersdal, G. 1957b. Mesh selection results for cod, haddock, and redfish. Ibid.

Saetersdal, G. 1957c. Selectivity of long lines and hand lines. Ibid.

Templeman. W. 1957a. Selection of haddock, cod, and American plaice. Ibid.

Templeman, W. 1957b. Selection of redfish. Ibid.

Templeman, W. 1957c. Selection of witch flounder. Ibid.

Templeman, W. and A. M. Fleming. 1956. The Bonavista Longlining Experiment, 1950-1953 Fish. Res. Board of Canada, Bull. 109.

Todd, R. A. 1911. Covered net experiments. North Sea Fish. Invest. Comm. 1906-1908. Third Report. (Southern area) on fishery and hydrographical investigations in the North Sea and adjacent waters. Mar. Biol. Assoc., United Kingdom, pp. 177-206.

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TWO NEW SPECIES OF BATHYLAGUS FROM THE WESTERN NORTH ATLANTIC WITH NOTES ON OTHER SPECIES

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While reviewing the Atlantic bathylagids for the forthcoming volume of "Fishes of the Western North Atlantic," two apparently unnamed species were encountered and are herein described as new. In addition, notes on several related bathylagids are presented.

BATHYLAGUS COMPSUS, sp. nov.

Figure 1

Bathylagus glacialis Beebe (*non* Regan), 1933, p. 114.

Holotype. U.S. National Museum 171755, 44.4 mm. in standard length; collected by Richard H. Backus on board the "Blue Dolphin," haul RHB 457, July 17-18, 1953, Isaacs-Kidd midwater trawl. Trawl down at 2255 hours, up at 0210 hours. Depth 69.5 m. Locality, within a circle 12 miles in diameter with the center at 39° 45′ N., 71° 08′ W. *Paratype:* USNM 171754 (1), 38 mm. in standard length; data as for the holotype.

Diagnosis. A *Bathylagus* with an extensive gill opening, reaching almost halfway up the side of the body; an anal fin base longer than the length of the caudal peduncle; and dark pigment present on the margins of the scale pockets.

Counts and measurements. Measurements given as per cent of standard length, holotype first, followed by the paratype in parenthesis. Dorsal 11 (10), anal 19 (20), pectoral 9 (9), ventral 9 (10), branchiostegals 2 (—); preanal 75.9 (76.8), preven-

tral 52.5 (52.1), predorsal 47.3 (50.0), prepectoral 27.0 (—), head length 25.0 (26.3), snout 5.6 (5.3), eye 10.0 (9.2), greatest body depth 16.9 (15.3), least depth of caudal peduncle 6.3 (6.6), dorsal fin base 8.8 (6.8), anal fin base 16.9 (15.0), interorbital 9.0 (—).

Description. A graceful, elongate fish with the greatest depth a short distance behind the head. The dorsal profile of the head descends from the nape to the interorbital in almost a straight line. It curves downward near the anterior edge of the orbit and

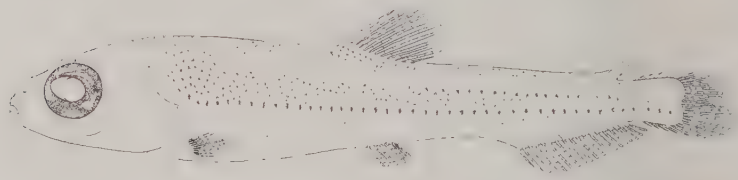

Figure 1. USNM 171755. Holotype of *Bathylagus compsus.*

descends to a point above the nares where another inflection occurs causing the profile to drop more steeply to the upper lip. The dorsal rim of the orbit does not enter the dorsal profile in the larger specimen but does in the smaller. The ventral profile of the head rises more gently than the dorsal profile descends. The interorbital area is broadly concave between the supraorbital canals. The maxillary extends back to a vertical from a point slightly in front of the anterior edge of the orbit. Minute papillae are present on the ventral margins of the maxillary and premaxillary. The jaws are rounded and subequal.

The eyes are directed laterally and lack adipose eyelids. A crescent of white tissue is present over the iris of the posterior half of the eye.

The height of the gill opening is slightly less than half the greatest height of the body and extends beyond the dorsal edge of the pectoral fin base by a distance equal to two and one-half times the length of the pectoral fin base. In his description of post-larvae of this species, Beebe (1933, p. 119) stated "gill openings characteristically small"; however, he gave no quantitative data, nor did he discuss this character in larger specimens.

The pectoral fin inserts a short distance behind the head on the ventrolateral contours of the body. The dorsal fin originates close to the midpoint of the body and has its base raised above the body. The ventral fins insert on the ventral surface of the body under the posterior part of the dorsal fin base. The anal fin base is set off from the body and is longer than the dorsal fin base and longer than the length of the caudal peduncle. The adipose fin is placed over the posterior end of the anal fin base. The fins are all broken off short.

The pigmentation of specimens in alcohol is striking and serves as an important diagnostic character, at least in adolescent specimens. The ground color is a light yellow-brown. The muzzle, the opercular apparatus and a ring around the orbit are dark brown. The opercle is overlaid with an iridescent sheen and is probably silvery in life. The iris is iridescent gun-metal blue and may also be silvery in life. The dark lining of the peritoneal cavity shows through the body wall and outlines the body cavity. A single row of large, dark chromatophores runs the entire length of the body slightly below the lateral line. A second and less distinct line parallels the first line a short distance above the lateral line. The right side of the paratype shows a striking resemblance to Beebe's (1933, p. 118) figure of an adolescent specimen. The left side of the paratype and both sides of the holotype vary in that the anterior portion of the upper line is lost in a scattering of smaller, lighter chromatophores. The venter is lightly peppered with small, dark chromatophores which are more densely distributed on the dorsum. Brown pigment cells are also present on the dorsal surface of the head behind and before the interorbital area and on the cheeks. The caudal, dorsal and adipose fins have scattered brown chromatophores, while the anal, ventral and pectoral fins are immaculate or bear only a very few pigment cells. In both specimens the posterior half of the body has the ragged remnants of scale pockets colored by large, dark chromatophores (not shown in Fig. 1).

Relationships. Bathylagus compsus appears most closely related to *B. nigrigenys* and *B. longirostris,* the only other known species of *Bathylagus* with extensive gill openings and elongate anal fin bases. The types of *B. compsus* differ from specimens of *B. nigrigenys* of comparable size in having more anal rays, 19

to 20 in *compsus,* 13 to 17 in *nigrigenys;* a shorter preventral distance, 52.1 to 52.5 in *compsus,* 56.7 to 61.4 in *nigrigenys;* in having a less deep body, 15.3 to 16.9 in *compsus,* 18.9 to 22.6 in *nigrigenys.* In addition, adolescent *nigrigenys* apparently lack the striking pigment pattern found in *compsus.* Other less trenchant differences are also present.

I have examined neither adolescent specimens of *B. longirostris* nor adult specimens of *B. compsus* and so hesitate to compare proportional measurements; however, *B. longirostris* differs markedly from *compsus* in its complete lack of pigment on the scale pockets.

Discussion. In his studies on Bermuda *Bathylagus,* Beebe (1933) identified one of the forms upon which he reported as *Bathylagus glacialis* Regan, a species originally described from the Antarctic. More recent studies by Norman (1937) and Cohen (MS.) strongly suggest that *B. glacialis* Regan is a synonym of *B. antarcticus.* I have examined a series of *B. antarcticus* from southern waters, and I find they differ from Beebe's descriptions of his Bermuda material. Unfortunately, I have not been able to obtain Bermuda specimens for direct comparison; however, the two specimens at hand differ so markedly from *B. antarcticus* (which is probably restricted to far southern seas) and agree so well with Beebe's description that I feel no qualms at referring Beebe's *glacialis* to *Bathylagus compsus.*

Beebe (1933) also presented an osteological study of this species, and there seem to be a number of discrepancies between his findings and those of Chapman (1943), who presented an osteological study of *Bathylagus pacificus.* The differences appear so marked that they could be used to separate genera or even higher taxa. I was fortunate in having at my disposal the identical cleared and stained specimens upon which Beebe based his descriptions (Stanford University 45302, from Bermuda) and I was able to note several points which require comment. These are briefly noted since they are of some importance in the classification of the bathylagids. 1. The frontals: Beebe states that the frontals are fused and he also figures them as such. I find that the frontals are not fused but instead are slightly separated in the midline. The underlying cartilage has taken up some of the stain and the edges of the bone are difficult to see

unless they are gently lifted. 2. The sphenotic: The bone which Beebe labels the pterotic in his dorsal view of the skull (Fig. 38) is actually the sphenotic and is so labeled in the lateral view (Fig. 36). 3. Supramaxillary: Beebe shows supramaxillaries in Figure 36, although he does not mention them in the text. I find no supramaxillaries, but instead a more heavily stained ridge which may have been mistaken for a joint. 4. Branchiostegals: Although he shows two branchiostegals in all of his figures and I find two branchiostegals in his specimen, Beebe gives three or four branchiostegals as a generic character. I know of no species of recent *Bathylagus* with other than two branchiostegal rays. Hubbs (1919) notes a single branchiostegal ray in *Bathylagus pacificus;* however, I have found two in this species. Chapman (1943) also reports two.

With regard to general shape and placement of bones, I find *Bathylagus compsus* in good agreement with Chapman's account of *B. pacificus.* Since Beebe did not dissect his specimen, his account of the deeper bones of the skull is necessarily sketchy.

The name *compsus* is from the Greek *kompsos,* elegant or pretty, and refers to the general appearance of this attractive species.

Bathylagus greyae, sp. nov.

Figure 2

Holotype. Chicago Natural History Museum 49730, 71 mm. in standard length; collected by the "Caryn," haul 38, August 6, 1948, 35 foot otter trawl. Trawl in at 2245 hours, out at 0200 hours. Depth of haul 500-550 m., 1500 m. wire out, bottom depth 2000 to 2560 m. Locality, Bermuda, 32° 13.5′ N., 64° 32.5′ W.

Paratype. Stanford University 50974 (1), 35.5 mm. in standard length, collected by the Bermuda Oceanographic Expeditions of the New York Zoological Society, 1929-1930, net 35, April 24, 1929. Net down at 9:54 A.M., duration of haul 3 hours, 36 minutes. Depth of haul 1646 m. to surface. Locality, Bermuda, an 8 mile circle with its center at 32° 12′ N., 64° 36′ W.

Diagnosis. A *Bathylagus* with an extensive gill opening, reaching more than halfway up the side of the body; an anal fin base equal to or shorter in length than the length of the caudal peduncle; and dark pigment present on the margins of the scale pockets.

Counts and Measurements. Measurements given as per cent of standard length, holotype first, followed by the paratype in parenthesis. Dorsal 11 (13), Anal 13 (13), pectoral 12 (13), ventral 10 (11), branchiostegals 2 (—), gill rakers on lower arm of first arch in holotype 16, preanal 81.0 (79.1), preventral 58.4 (61.1), predorsal 48.2 (50.7), prepectoral 28.9 (32.7), head length 25.3 (29.6), snout 5.9 (7.0), eye 9.4 (see description for comments on eye of paratype), greatest body depth 13.4 (16.9), least depth of caudal peduncle 8.4 (8.4), dorsal fin base 12.0 (11.8), anal fin base 9.7 (9.9), lateral line scales probably between 45 and 50 on both specimens.

Description. An elongate and much laterally compressed fish with the greatest depth behind the head, tapering very little to the caudal peduncle. The dorsal profile of the head slopes gently downward in almost a straight line from a point behind the eye to a point near the nostrils, from whence it descends more steeply. The dorsal rim of the orbit projects into the dorsal profile of the head. The interorbital area between the supraorbital canals is broadly rounded. A well developed pineal apparatus

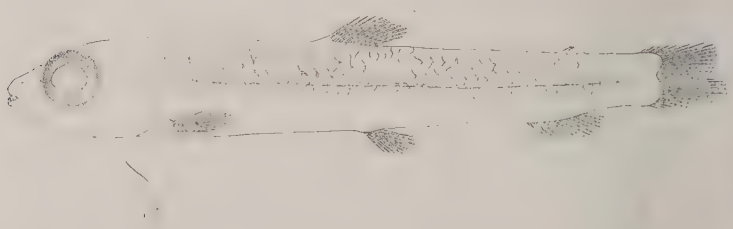

Figure 2. CNHM 49730. Holotype of *Bathylagus greyae* (this figure is a reconstruction of the somewhat distorted holotype and should not be used for measurements). Lower figure is of the opercle of *Bathylagus ochotensis*.

is present and is visible through a clear window in the deeper pigmentation of the braincase. A broad ring of dense pigment about the window gives the appearance of an iris. The posterior edge of the maxillary does not reach a vertical from the anterior edge of the orbit. Minute papillae are present on the epidermal covering of the maxillary, premaxillary and dentary. The jaws are rounded and equal.

The mouth of the holotype is damaged, making it difficult to discern any details of dentition; however, the single row of upper teeth are conical and apparently restricted to the head of the vomer. The compressed dentary teeth are smaller than the vomerine teeth with the exception of a pair of small, spike-like teeth which project at the symphysis of the dentaries.

The eyes are directed laterally and lack adipose eyelids. A crescent of white material is present over portions of the iris. The left eye of the paratype presents certain peculiarities. It has a horizontal diameter of 3.5 mm. compared to 4.2 mm. for the right eye. In addition, the left eye has two small lenses visible through the pupil.

The height of the gill opening is more than half the greatest height of the body and extends beyond the dorsal edge of the pectoral fin base by a distance equal to about two and one-half times the length of the pectoral fin base in the holotype and about one and one-half times in the paratype.

The pectoral fin inserts a short distance behind the head on the ventro-lateral contours of the body. The dorsal fin originates close to the mid-point of the body. Both the dorsal and anal fin bases are set off from the body. The dorsal fin base is slightly longer than the anal fin base. The anal fin base is equal in length to the length of the caudal peduncle. The ventral fins insert on the ventral surface of the body under the posterior part of the dorsal fin base. The dorsal adipose fin is placed over the center of the anal fin base. A weak ventral adipose fin is present directly anterior to the vent of the paratype.

The ventral half of the holotype has a light, straw-colored ground color. The dorsal half of the fish is brown, while the opercle and the snout are dusky. Small, dark-brown chromatophores are scattered at random over the sides of the fish on a field of still smaller, more densely distributed, light-brown chromatophores. The sides of the head and all of the fins are lightly peppered with dark-brown pigment cells. Dark pigment is also thickly distributed on the margins of the scale pockets. Some of the scale pockets bear remnants of a purplish, translucent material which is common to a number of *Bathylagus* species. The paratype has faded badly, and little in the way of pigmentation remains.

Relationships. B. greyae is closest to *Bathylagus ochotensis* (which has *B. nakazawai* as a synonym, Cohen, MS.). It differs in having a greater preanal distance, 81.0 in the type of *greyae*, 73.7 and 77.6 in two specimens of *ochotensis* of comparable size; in having a longer preventral distance, 58.4 to 61.1 in *greyae*, 51.3 to 57.1 in 17 specimens of *ochotensis;* in having the anal fin base slightly shorter than the dorsal fin base, while in *ochotensis* the anal fin base is longer than the dorsal fin base. In addition, the postero-ventral margin of the opercle is smooth in *greyae,* while in *ochotensis* it is drawn out into five, finger-like projections (Fig. 2).

This species is named for Mrs. Marion Grey of the Chicago Natural History Museum in recognition of her contributions to the study of deep-sea fishes.

Bathylagus longirostris Maul

Until the present time this species has been known only from the type, apparently taken at Madeira. I have examined a single specimen from the Gulf of Mexico, south of Pensacola, Florida, collected by the U.S. Fish and Wildlife Service vessel "Oregon" and deposited in the Chicago Natural History Museum. In addition, two specimens collected in the Central Pacific (30° 16.5′ N., 179° 54′ E. and 29° 54′ N., 168° 32′ W.) by the Pacific Oceanic Fishery Investigations (POFI) are apparently referable to *B. longirostris.* Descriptions of the above specimens will be included in a projected revision of the Bathylagidae.

Bathylagus bericoides (Borodin)

This species has been previously recorded three times, each from the Western North Atlantic. I have examined an unrecorded specimen from Bermuda (SU 42715) and a specimen from "Oregon" st. 1028 (Chicago Natural History Museum). The latter was provisionally identified as *Bathylagus microcephalus* by Springer and Bullis (1956). *B. bericoides* is also present in POFI collections from the central Pacific (39° 31′ N., 178° 54′ W.; 39° 08′ N., 164° 51′ W., and 42° 16′ N., 179° 52′ W.). These specimens will be treated at greater length in the future.

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LITERATURE CITED

Beebe, William

1933. Deep-sea fishes of the Bermuda Oceanographic Expeditions. Family Argentinidae. Zoologica (New York), **16:** 97-147.

Chapman, Wilbert M.

1943. The osteology and relationships of the bathypelagic fishes of the genus *Bathylagus* Günther with notes on the systematic position of *Leuroglossus stilbius* Gilbert and *Therobromus callorhinus* Lucas. Journ. Washington Acad. Sci., **33:** 147-160.

Hubbs, Carl L.

1919. A comparative study of the bones forming the opercular series of fishes. Journ. Morph., **33:** 66-71.

Norman, John R.

1937. Fishes. Rep. Br. Aust. N.Z. Antarct. Res. Expedn. 1929-31, Adelaide, (B) **1** (2): 49-88.

Springer, Stewart and Harvey Bullis

1956. Collections by the *Oregon* in the Gulf of Mexico. Dept. of the Interior. U.S. Fish and Wildlife Service. Spec. Scient. Repts. — Fisheries, **196:** 1-134.

Taaning, Aage V.

1931. Postlarval stages of *Bathylagus* from the North Atlantic. Vidensk. Medd. fra Dansk Naturh. Foren., **92:** 269-274.

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The measurement of performance of salmon in fishways

Faced with the prospect of providing fishways for a large number of dams, knowing that upon our success or failure depends the success or failure of important fishery resources, we must carefully assess our present knowledge of the behavior, abilities and requirements of fish as they relate to fish passage.

What are "fishways"? As we use the term in its broadest sense, fishways include a wide variety of structures and devices used to assist in passing migrating fish over or around obstacles such as dams. Fishways may consist of pools, collecting systems, channels, orifices, locks, hauling cars, brails, tunnels, weirs, traps, elevators, live cars, barges, louvers or baffled flumes, in all sorts of combinations.

To properly design "fishways" we should be able to predict the behaviour and performance of migratory fish in all of the diverse situations with which they may be confronted. To do this a detailed knowledge of all the factors that can modify the direction or rate of fish movement is required. We should know, for example, the water properties that are attractive to fish, the spatial relationships that affect fish movement, the hydraulic conditions conducive to or interfering with fish passage, the role of light and vision in the ascent of fish ladders, the reaction of fish to change in light and flow conditions, and the importance of sequential experience. We should know the seasonal and diurnal patterns of fish activity, fish swimming abilities and persistence, their metabolic requirements and limits of stress, their sensory capabilities and their ability to learn, their reactions to various degrees of crowding by other fish and the number of fish per unit time that can pass through various types of fishways.

These are but examples of the broad range of items on which we need information, precise information. If our concern were for only one dam and we were uncertain of the size of fishway required, we might design it with huge safety factors in size and thus build it two or three (or perhaps five) times as large as it need be. If we were uncertain of the reaction of the fish to one type of fishway, we might include a second set of fishways of a

different type (e.g., both fish ladders and fish locks). If we were not sure that fish would remain in a particular type of collection channel, we might provide a separate transportation channel in back of the collection channel as insurance that fish on the far side of the system would not leave the fishway. The lack of precise information on fish behavior can in this way result in enormously increased fishway costs. Multiplied by the large number of dams that might be erected on a major river system, the total cost of over-designed fish passage facilities could reach such staggering proportions that they might no longer be economically justifiable in terms of the resources we are attempting to protect. Similarly, lack of precise information could permit the design of inferior fishways and minor delays or injuries that would be unnoticed or of little significance at one or a few dams might prove disastrous to a fishery when repeated at many dams. Detailed, accurate information on salmon behavior and performance is essential if we are to design economical fishways with confidence.

How to acquire this information is our problem. The subjects of our interest are large, active migrating fishes available for only a few months of the year. They are not convenient laboratory animals and there is always the danger that the shock of capture, removal from its natural medium and transportation to a conventional laboratory might modify the very responses we wish to measure. A logical thought is to attempt to study the fish in our present fishways. This also has severe drawbacks. If we depend on observation alone, we are limited to fishway conditions that already exist. If, however, we resort to experimenting in a functioning fishway there is the constant threat that if an unfavourable condition is created it may seriously impede or block the fish run. An alternative to this latter approach has been undertaken at Bonneville Dam on the Columbia River. There a special type of laboratory has been constructed on a bypass into which salmon are diverted from one of the major fishways. Salmon swim into this unique laboratory where they can then be subjected to full scale fishway situations under controlled experimental conditions without jeopardizing the passage of the main fish run. After fish pass through the experimental fishways and their performance has been recorded, they swim out of the laboratory and re-enter the main fishway.

The laboratory, called the Fisheries-Engineering Research Facility, consists of a level experimental flume (Figure 1) 104 ft. long, 24 ft. wide and 17 ft. deep, with a fish collection pool 50 ft. long and 24 ft. deep at the downstream end, and a flow introduction pool 40 ft. long at the upstream end. It has a water supply and discharge system that is independent of the main fishway and is capable of delivering and discharging more than 200 cubic feet per second for tests involving high water velocities. Light control is provided by a completely covered building and eighty 1000-watt mercury vapor lamps that under standard operating conditions produce illumination approximately equivalent to a cloudy bright day. Various types of fishway structures are erected in the experimental flume while it is dry, then water is introduced and the gates to the main fishway are opened to permit the entry of fish.

Funds for the laboratory were provided by the U.S. Army Corps of Engineers as a part of their effort to find an economic solution to their fish passage problems in the Columbia River. The selection of research items to be assigned priority or to be studied in greatest detail is therefore guided by the Corps' recommendations as to which have the greatest potential importance from the standpoint of construction and operation costs. For the first year's research three items were assigned priority, a measure of fishway capacity in a conventional pool type fishway, a study of the effect of gradient on rates of fish passage, and information on the relative attraction of water velocities.

The study of the effect of gradient on rates of fish passage was conducted by comparing rates of fish passage in two 12 ft. wide fishways. After tests for uniformity in the rates of

passage when the two fishways were identical, the gradient of one of the fishways was modified while the other remained as a control in which to detect diurnal and seasonal variations. In this way the rate of passage through a "standard" fishway (similar to fishways at Bonneville Dam, 16 ft. pool length, 1 ft. rise between pools) with a gradient of 1:16 was compared with the rate of passage through three varieties (pool length 16 ft. and rise 2 ft. between pools, pool length 12 ft. and rise 1.5 ft., pool length 8 ft. and rise 1 ft.) of pool type fishways with a gradient of 1:8.

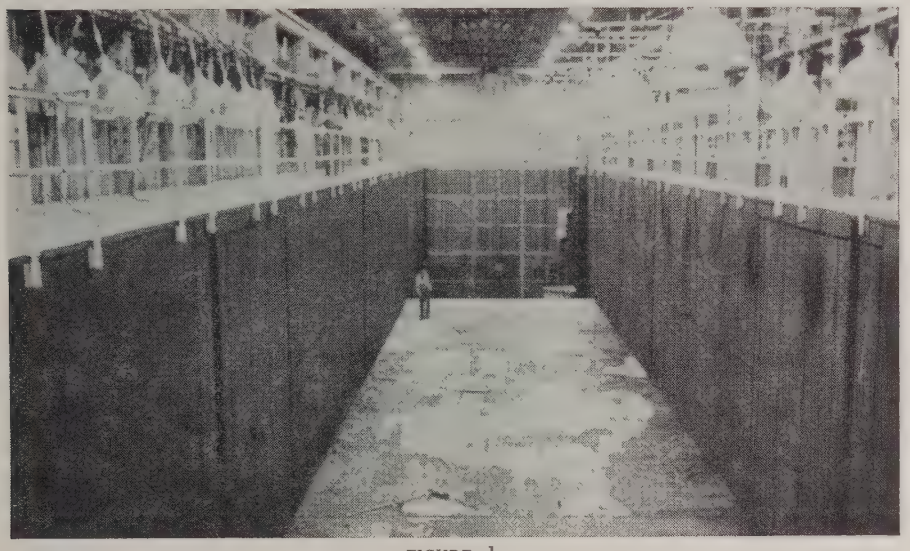

FIGURE 1.

EXPERIMENTAL FLUME (LOOKING TOWARD FISH COLLECTION POOL).

The "capacity", or maximum number of fish that can be passed per unit time, of a standard pool type fishway was measured in a fishway 6 ft. wide (Figure 2) that was created by installing a wall in the 12 ft. fishway used as a control in the gradient studies. Fish entering the laboratory were accumulated in the fish collection pool below the test fishway and then released as a group into the fishway. A brail was raised from the floor of the fish collection pool to within 2 ft. of the holding pool surface just prior to release to insure that the fish left the collection pool and entered the test fishway.

In experiments to determine which water velocities are most "attractive" to fish a choice technique was used in which the fish were presented with a choice between two channels with different water velocities. The relative number of fish selecting each channel was used as an index of the relative "attractiveness" of each water velocity.

The information that is available from the first season's operation of the laboratory at Bonneville is most encouraging from the standpoint of potential economies in fishway design. However, each series of tests is designed to provide specific information bearing directly on a part of a larger fishway problem and it may require several seasons of research before enough data is assembled to apply the information with confidence. For example, in the fishway gradient study the data show a higher rate of passage in one of the fishways with a gradient of 1:8. This is of great interest from the standpoint of construction cost for a fishway with a gradient of 1:8 would only need to be half as large as a fishway with a gradient of 1:16. However, because the tests were made with only a short segment of a fishway the possibility that the accelerated rate may be due to increased turbulence must

FIGURE 2.
FISHWAY USED FOR STUDY OF FISHWAY "CAPACITY" (LOOKING UPSTREAM TOWARD FLOW INTRODUCTION POOL).

be considered. Experiments of a different sort, using a "continuous" fishway technique are planned to determine if fish might become excessively fatigued in a longer fishway with a gradient of 1:8. Data from the tests of fishway capacity indicate that surprisingly large numbers of fish can be passed by a fishway of modest size. This information also gives promise of sizeable reductions in fishway construction costs if the information is verified under circumstances closer to those prevailing in longer fishways.

Other observations were made that have potential significance from the standpoint of fishway design. In measuring the performance of salmon in the experimental fishways throughout the season, it becomes apparent that performance may vary with the season. Fall chinooks were faster and more consistent than spring chinooks, while the rate of passage for steelhead appeared to slow down as the season progressed. This would seem to indicate that the "capacity" of a fishway could also vary with the season. The effect of a change in flow pattern was demonstrated on several occasions during capacity tests when fish movement almost ceased for several minutes when the flow patterns changed from plunging flow to a streaming flow. Such responses emphasize the importance of stable flow conditions as a design criterion. Individual fish showed a tendency to cross weirs next to a wall; however, the selection of a wall at each weir seemed to be almost at random, suggesting a tendency to explore each pool. This tendency to explore might result in unnecessary delay if a fishway were too large. As an example, in conducting experiments at the Fisheries-Engineering Research Facility, it was necessary to have fish swim in and out of the laboratory with a minimum of delay. One of the most effective methods of keeping the fish moving was to restrict the area in which the fish could explore by means of nets or brails.
(At this point a 15-minute portion of the motion picture film record of the 1956 experiments

at the Fisheries-Engineering Research Facility was shown).

The measurement of fish performance in full scale fishway situations should be an important part of any comprehensive research program involving fish passage. There is probably no other way to breach the enormous gap between our knowledge of the performance of salmon in basic laboratory studies of fish physiology and psychology and our knowledge of the performance of fish in actual fish passage facilities. It is entirely possible and reasonable to measure the performance of fish in full scale fishway structures in the Fraser and in Alaskan rivers even before any dams are constructed. Solutions have been proposed for fish passage problems at high dams and at low dams. These should be tested before they are accepted as solutions and set in concrete. By acquiring a knowledge of fish reactions to specific fishway situations beforehand much of the guess and gamble of new fishway designs could be eliminated.

DISCUSSION

MR. CAMPBELL: (Referring to an experiment shown in the motion picture film record): How long was that area of eight feet per second velocity?

DR. COLLINS: The length of the channel having a velocity of 8 ft. per second was about 60 feet. In addition, the fish approached the channel through water velocities at approximately 8 ft. per second so that the fish actually had to swim a distance of about 80 ft. at that velocity. We plan to measure the response to even higher velocities this year. Last year's tests were made with fall run fish that were rather large fish.

DR. HOURSTON: If offered a choice between four feet per second and eight feet per second, which would they take?

DR. COLLINS: More of the fish were choosing the higher velocity in the experiments last fall. The tests were run at the very end of the season when few fish were available so that we tested all that came along. Our sample was small and included both steelhead and chinook salmon. There was also a wide variation in fish size with a greater number of large fish. It is possible that the response was due to the larger fish selecting the higher velocity. We will have an opportunity to examine the relation of fish size to choice of water velocity in more detail this year.

MR. VERNON: In regard to the difference between fall chinooks and spring chinooks, is there any indication that this would be caused by temperature?

DR. COLLINS: It may be related to temperature. However, there is also a difference in the state of maturity that may be important. The spring chinooks have a longer way to migrate and they are not as mature as the fall chinook when they pass Bonneville. On the basis of our exploratory tests in the fall of 1955, we anticipated that it would take about 2 or 3 minutes per pool for chinooks to pass through our control fishway. We were puzzled to find them taking from 5 to 20 minutes per pool in the spring of 1956. However, the pattern of slow movement with great individual variation was repeated again in the spring of this year.

MR. ALDERDICE: Is there much range in temperatureà

DR. COLLINS: Yes, the water warms up from about 50° to 65°F. during the season. Unfortunately, we are unable to regulate either water temperature or turbidity for our experiments. We have to take the river water as it comes.

MR. VERNON: Do the coarse fish successfully negotiate at eight feet per second?

DR. COLLINS: I doubt if we have any information on coarse fish in water of that velocity. There may have been a few coarse fish, but the tests were made at the very end of the salmon run and as far as I can recall, our only data is on the reactions of a few late steelhead and fall chinooks. We expect to run velocity tests in July or August this year when more coarse fish are present.

DR. FOERSTER: Do you anticipate carrying out any chemical blood or fat tests?

DR. COLLINS: We hope to get the collaboration of specialists for that. It is difficult to see what we can do of that nature with the type of experiments we are running this year. There is no indication of any fish fatigue in the short segments of fishway with which we are working. Next year we plan to examine fish persistance in ascending fishways by means of "continuous" fishway techniques and we hope that we can interest the group from the University of Washington in making related chemical studies.

DR. FOERSTER: Would you kindly relate your work on this point now?

MR. PAULIK: One of the relatively interesting points was the different swimming abilities of the various species. We tested steelhead and coho from the same streams under identical conditions at a number of different water velocities. The steelhead were able to swim much longer than coho at more than ten feet per second. Steelhead were able to hold

their position in water velocities up to 12 ft. per second whereas coho were not. We sampled a sockeye run at a number of dams on the Columbia River as they migrated upstream last summer. We transferred these fish back to the University and measured their swimming abilities at the various sites. We found a tremendous variation between Bonneville Dam and Rock Island Dam during the first part of the migration. After the first 450 miles up the river they seemed to at least maintain a stable level of ability. After that they turned up the Wenatchee River. We took samples after they left Lake Wenatchee and after they had entered the spawning streams and at that time their swimming ability was at a much lower level.

DR. BRETT: I wonder whether you would care to define what is meant by attraction?

DR. COLLINS: Going on the assumption that fish have a preference for some range of water velocities, the water velocities that would cause fish to approach a channel or a fishway could be said to have attraction. The term attraction water is commonly applied to the auxiliary water supplied at fishway entrances to gain the attention of fish and to stimulate them to enter the fishway. The velocity of water coming from the entrance of a fishway can be controlled at, let us say, two, four or six feet per second.

However, large volumes of attraction water are tremendously expensive. If we find that fish are attracted by higher velocities it may be possible to use a high velocity jet. Even in luring fish from the fishway into our Research Facility we have to consider the relative velocity of the entrance water.

DR. FOERSTER: In regard to your remarks about the ferrying of fish—to withstand temperature and current, is there not an emotional stress there when you take these fish back to the University of Washington. They are then several hundred miles away from their spawning grounds. I am interested particularly in emotional want.

DR. COLLINS: I think one of the answers to that question might be obtained by comparing the results of tests made after fish actually swim into the test area. This would give us a relative scale of abilities which might possibly be an indirect measure of emotional stress.

DR. FOERSTER: If there is any homing tendency, might it not be stronger as the fish mature and as the water quality becomes different? I think most of the tests at the University are forced—are they not, Gerry?

DR. COLLINS: Yes, the fish are motivated by both a light and a barrier which forces them to swim until they are exhausted.

MR. PAULIK: When we transport the fish we don't lose any, and after two days they seem fully recovered. However, realizing this problem, we are going to try to do some work right at the river to see if we can duplicate the experiment at the laboratory.

DR. COLLINS: One of the differences in the two techniques is the difference in motivation. In the laboratory the fish are compelled—so far in the Research Facility simple swimming tests have used a voluntary response. We need to know both what a fish can do and what it will do.

DR. THOMPSON: Did you say how soon a fish would present itself again after once turning back?

DR. COLLINS: No. Actually, I don't believe we know. I think, talking about the entire group sounding, that it would be difficult to know when a particular fish did present itself again unless it was a tagged fish. When there is a fright reaction, though, it takes at least 15 minutes before any fish will come out of the pool.

DR. THOMPSON: From my own experience, a period of delay before presentation of a thoroughly exhausted fish is more than 30 minutes; it is more like three days. I am particularly interested in the rate of recovery, not only in regard to our fish in Alaska, but in regard to the general problem of deep sea tagging. When a fish is thrown overboard after thorough exhaustion, when does he recover? You are not only facing a lethal affect, but you are also facing the ability of the fish to recover.

DR. COLLINS: We should have some information on that. Mr. Trefethen has been working at Bonneville trying to measure the effect of tagging fish with sonic tags. As I recall, he thought it took about 24 hours for the fish to recover.

MR. TREFETHEN: Yes, about 24 hours, that is, if the fish were not excited or were not disturbed in any other way. We did find that for the excited fish, the rate of movement was much less than if they were not disturbed.

DR. JOHNSON: I am interested in the basis for your judgment—your criteria as to what are considered favorable results. For example, if we called for lunch here, the rate of passage out of here might be one figure—I was wondering if you shouted "FIRE" it might be a different one. I had in mind also that if I went out of here at the shout of "FIRE" I might be somewhat out of breath and perhaps I shouldn't be as able to "migrate" successfully to lunch.

DR. COLLINS: I assume you are referring to the technique of using a brail to crowd fish in the tests of fishway capacity. The result may be a not completely voluntary action on the part

of the fish. The raising of the brail and the resultant crowding probably acts as a stimulus that starts fish moving. However, this was a way of getting enough fish into the test fishway to crowd it. I have seen large schools of fish at the foot of a fishway apparently acting in much the same way as the fish do in entering our test fishway. As to the possible after-effects of an unusual expenditure of energy in a fishway, I can only speculate.

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INCIDENCE AND LIFE HISTORY OF PARORCHIS ACANTHUS, A DIGENETIC TREMATODE, IN THE SOUTHERN OYSTER DRILL, THAIS HAEMASTOMA

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Abstract

This paper is the initial report of a program to develop biological control of the Southern Oyster Drill, Thais haemastoma, cause of considerable economic loss in some areas on the Gulf of Mexico.

Information on the life cycle, known hosts, reported localities, synonymy, and morphological descriptions of developmental stages of the digenetic trematode Parorchis acanthus has been compiled from various sources.

The pathology of Parorchis infection in T. haemastoma is briefly described and figured.

Preliminary data indicate that incidence of natural infection of P. acanthus in T. haemastoma is about 2% in Northwest Florida, 3.4% in Mississippi and less than 1% in Texas. All natural infections were massive, parasite larvae constituting 70 to 90% of the liver.

Parorchis infections experimentally induced in herring gulls (Larus argentatus), in ring-billed gulls (L. delawarensis), and in oyster drills are reported. Sexually mature Parorchis adults were first recovered from the cloacas of four out of four gulls 30 days after feeding each gull approximately 200 encysted metacercariae suspended in sea water. In oyster drills continuously exposed to droppings of Parorchis-infected gulls, the first infection was found on the 21st day of exposure and on the 33d day of exposure, four of 33 examined were infected. The elapsed time and the recovery of only first generation rediae indicate that these were true experimental infections.

Possible use of P. acanthus as a biological control agent for T. haemastoma is discussed.

Introduction

Although very few data have been published, the Southern Oyster Drill, Thais haemastoma, is probably responsible for extensive economic loss to the Gulf oyster fishery. In an attempt to develop a method of biological control, the natural enemies of this snail are being investigated. Scattered observations on the parasites of Thais have been reported in the literature. Few of the papers containing these observations were concerned directly with the parasites. Schechter (1943) reported the emergence of Parorchis acanthus cercariae from occasional Thais from Barataria Bay, Louisiana. Butler (1953) noted that at least two trematodes parasitizing Thais in Louisiana and in the Pensacola, Florida, area may cause considerable damage to the gonad. During a study of the reproductive cycle of Thais, Butler (1956) found some drills heavily infected with larvae of parasitic worms which damaged the gonad so badly as to render it unfit for cytological study. The latter two observations suggested the possibility of biological control of Thais populations. Accordingly, in the summer of 1956, a survey of the parasites of this drill was begun in hope of finding a parasite which could be used for this purpose.

In September, 1956, heavy infections of a larval digenetic trematode, later identified as Parorchis acanthus Nicoll, 1907, were found in the livers of drills from Gulfport, Mississippi, and a study of this worm was begun. Since then, the parasite has been found in a number of drills from Biloxi, Mississippi, from Pensacola, Florida, and from Galveston, Texas. This paper is the first report of these investigations.

Life Cycle of Parorchis Acanthus

The life cycle, based on the descriptions of Stunkard and Cable (1932) and Rees (1940), is shown in Figure 1. The sexually mature worm, living in the cloaca and bursa Fabricii of the herring gull, releases eggs, each of which contains a completely developed miracidium. The miracidium contains a single well-developed redia. The egg hatches immediately after release into the cloaca of the gull, and the miracidium is discharged in the feces of the gull into the water. If the free-swimming miracidium does not enter a snail host, it dies in less than a day. Upon finding a snail, the miracidium apparently enters the aperture of the shell, passes up between the shell and body of the animal, penetrates the tunica propria of the liver at the spire and disintegrates, releasing redia (Redia I). The germ balls of Redia I give rise to a second generation of rediae (Rediae II) which penetrate deeper into the liver, ultimately lodging in the connective tissue between the hepatic tubules. In massive infections, Rediae II also invade the gonad and, according to Stunkard and Shaw (1931), may cause parasitic castration in Urosalpinx cinerea. The germ balls of Rediae II develop into cercariae only, no additional

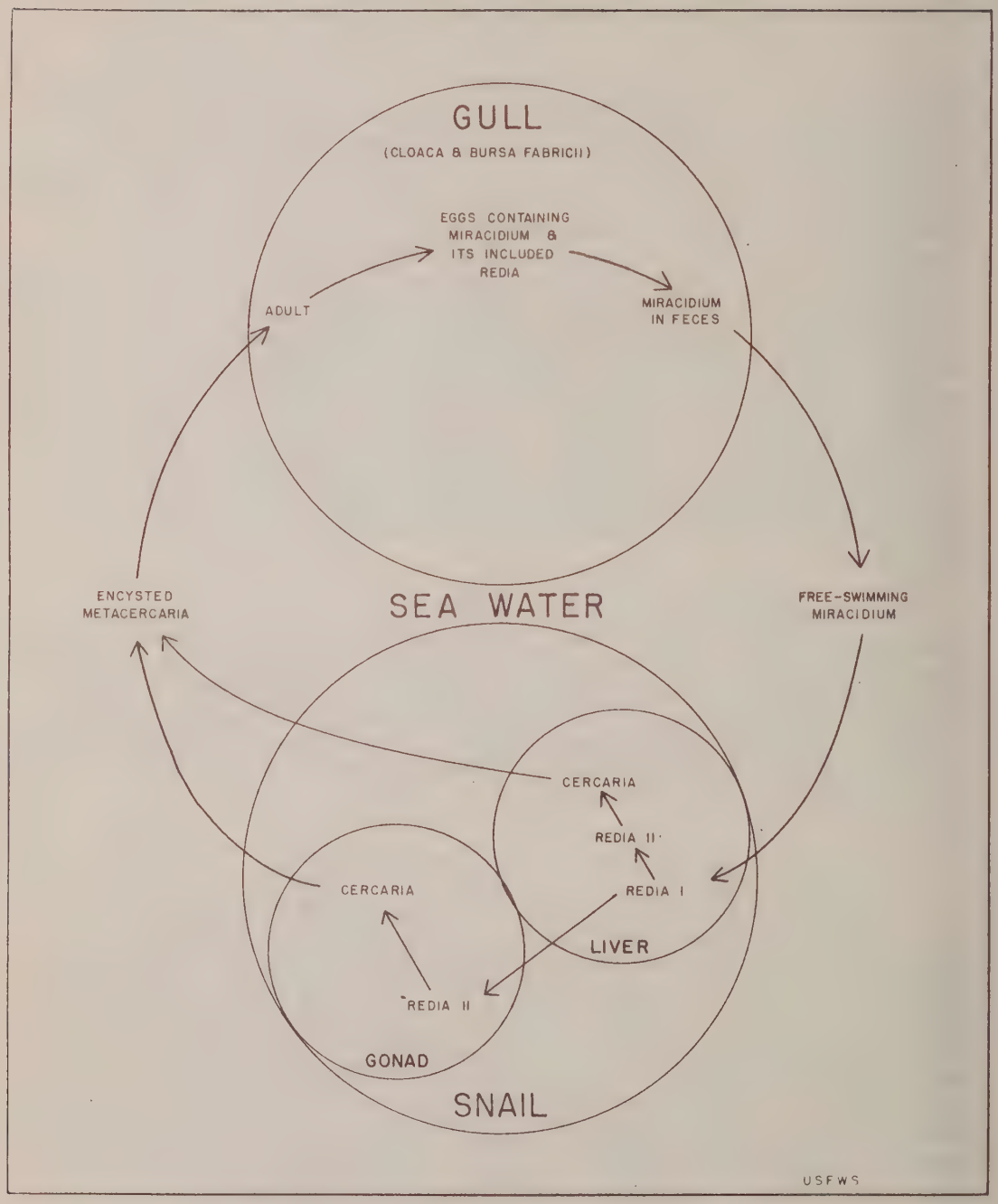

Fig. 1. Life cycle of Parorchis acanthus (based upon Stunkard and Cable 1932, Rees 1940).

generations of rediae being produced. The mature cercaria, released through the birth pore of Redia II, leaves the snail, swims about briefly in the water, then settles down on any available submerged object and rapidly secretes a double-walled cyst membrane about itself while detaching its tail. The larva is now an encysted metacercaria. The metacercaria, when attached to food, is ingested by the gull, passes through the digestive tract and excysts in the lower intestine. The juvenile worm attaches itself, by means of a powerful ventral sucker, to the wall of the cloaca, bursa Fabricii and, less commonly, the lowermost part of the intestine and develops into a sexually mature adult.

A list of hosts of P. acanthus, sites of infection in drills, localities from which infections were reported and authorities are given in Table 1.

Morphology of Parorchis Acanthus

The morphology of the different developmental stages had been described by a number of authors (Table 2) under the names of Zeugorchis acanthus, Parorchis acanthus, P. avitus, Cercaria sensifera, and C. purpurae. As far as I can determine from the literature, all are generally regarded to be synonyms of P. acanthus. I have seen all developmental stages, and although there are minor differences, my material is in general agreement with the published descriptions. A complete description of my material will be published elsewhere at a later date.

Effect of Larval Stages of Parorchis Upon Thais

Invasion of the snail host by any sizeable number of miracidia results in production of a very large number of second generation rediae (Figure 1). In all natural infections examined by dissection, rediae were easily seen with the naked eye through the transparent tunica propria covering the liver. In cross sections of unfixed livers they appeared as enormous numbers of tiny white wormlike objects interspersed among irregularly distributed small masses of liver tissue. All natural infections were rated massive, since 70 to 90% of the liver had been replaced by rediae. Any slight tear in the tunica propria permitted the escape of a flood of rediae and cercariae into the surrounding medium.

The gross appearance of cross sections of livers of infected and uninfected snails may be compared in Figure 2. The liver of the uninfected drill is variable in color, usually being light gray or beige, but may be very dark, almost black. Its consistency is like that of soft cheese. The surface is covered by a fairly tough tunica propria. The swollen liver of the infected drill is less variable in color, usually being lighter gray or light yellow. Its consistency is softer and its tunica propria more easily torn.

Table 1. Known hosts of Parorchis acanthus

HOST	SITE OF INFECTION	LOCALITY	AUTHORITY
ADULT STAGE			
Gulls			
Herring	Cloaca, bursa Fabricii	Scotland	Nicoll 1906
		Mass	Linton 1914, Cable 1937
		Wales	Rees 1939
		Florida	Unpublished
Ring-billed	Cloaca	Florida	Unpublished
Western		Calif	Penner 1957, pers. com.
Common	Rectum	Scotland	Nicoll 1907
Terns			
Common	Cloaca	Mass	Stunkard & Cable 1932
Roseate	Cloaca	Mass	Stunkard & Cable 1932
Shore birds			
Willett		Florida	Penner 1957, pers. com.
Dowitcher		Florida	Penner 1957, pers. com.
Water turkey		Florida	Penner 1957, pers. com.
LARVAL STAGE			
Snails			
Urosalpinx cinerea	Liver, gonad	Mass	Stunkard & Shaw 1931, 1932
Thais lapillus[1]	Liver, gonad	Wales	Rees 1939
Thais lapillus	Liver	Scotland	Lebour 1914, Lebour & Elmhirst 1922
		Wales	Rees 1937
Thais lapillus	Liver, gonad	Mass	Stunkard & Cable 1932
Thais haemastoma	Liver, gonad	Miss	Unpublished
		Florida	
		Texas	
		Louisiana	Schechter 1943
Littorina planaxis		Calif	Penner 1957, pers. comm.
Melogena sp.	Liver	Florida	Penner 1957, pers. comm.
Batillaria sp.		Florida	Penner 1957, pers. comm.
Cerithium sp.		Florida	Penner 1957, pers. comm.

[1]See Clench (1947: 86-87) for synonymy.

Table 2. Developmental stages, synonymy, and sources of morphological descriptions of Parorchis acanthus.

Developmental stage	Name given	Authority
Adult	Zeugorchis acanthus Parorchis acanthus Parorchis avitus P. avitus (immature)	Nicoll 1906 Nicoll 1907 Linton 1914, 1928 Stunkard & Cable 1932
Egg	Z. acanthus P. acanthus P. avitus	Nicoll 1906 Nicoll 1907 Linton 1914
Miracidium	Z. acanthus P. acanthus P. avitus	Nicoll 1906 Nicoll 1907, Rees 1940 Linton 1914
Redia	Cercaria purpurae C. sensifera P. acanthus	Lebour 1914, Rees 1937 Stunkard & Shaw 1931 Rees 1940
Cercaria	C. purpurae C. sensifera P. acanthus	Lebour 1907, 1914 Rees 1937 Stunkard & Shaw 1931 Lebour 1914, Rees 1937 & 1940
Metacercaria	C. purpurae C. sensifera P. avitus P. acanthus	Rees 1937 Stunkard & Shaw 1931 Stunkard & Cable 1932 Lebour & Elmhirst 1922

Fig. 2. A. Liver of uninfected drill, transverse section, X 7.5. Note homogeneous appearance of normal tissue. B. Liver of drill with massive Parorchis infection, transverse section X 7.5. Whitish objects occupying most of liver are parasite larvae, gray patches are remaining liver tissue.

A comparison of stained cross sections of the livers of infected and uninfected drills (Figure 3) reveals the extensive displacement of the liver tissue produced by developing rediae. The histopathology of liver infections is characterized by:

(1) extensive displacement and reduction of liver tissue to 10 to 30% of the surface area of the cross section;

(2) compression of liver tubules resulting in obliteration of most if not all of their lumina;

(3) presence of basophilic inclusion granules of uncertain significance in the cytoplasm of the large triangular cells of the hepatic tubules, revealed by hematoxylin-azure B-eosin staining;

(4) presence of certain cells, thought to be phagocytic blood cells, in groups next to some of the parasite larvae; and

(5) apparent absence of direct destruction of liver tubules by invading parasites.

Invasion of the gonad was observed in a few specimens. The gonad of the uninfected drill is cream-colored or dark beige to brown, its size and thickness varying according to seasonal changes in the reproductive cycle; that of infected animals has been thin or patchy and dark yellow or orange in color. Whether the differences observed are an effect of infection or constitute normal seasonal changes is uncertain at this time.

Some Results of Experimentally-Induced Infections with *Parorchis Acanthus*

Gulls:

One herring gull (*Larus argentatus*) and three ring-billed gulls (*L. delawarensis*), known by repeated examinations over a one-month period to be *Parorchis*-free, were used in this experiment. Large numbers of cercariae obtained by dissection of naturally infected drills were permitted to encyst on the bottom of a Petri dish of sea water. The encysted metacercariae were scraped free with a scalpel, suspended in sea water, and several hundred pipetted into the esophagus of each gull before feeding the daily meal of chopped fish (usually mullet). This treatment was repeated a week later in order to insure infection of all birds. The fish, obtained locally, were quick-frozen, cut up into small pieces, and stored at 0° F for several weeks to prevent possible infection of the gulls with fish parasites. The fish were thawed just before feeding time. At intervals of seven to ten days, the cloaca of each bird was aspirated carefully with a medicine dropper pipette and the aspirate examined for worms.

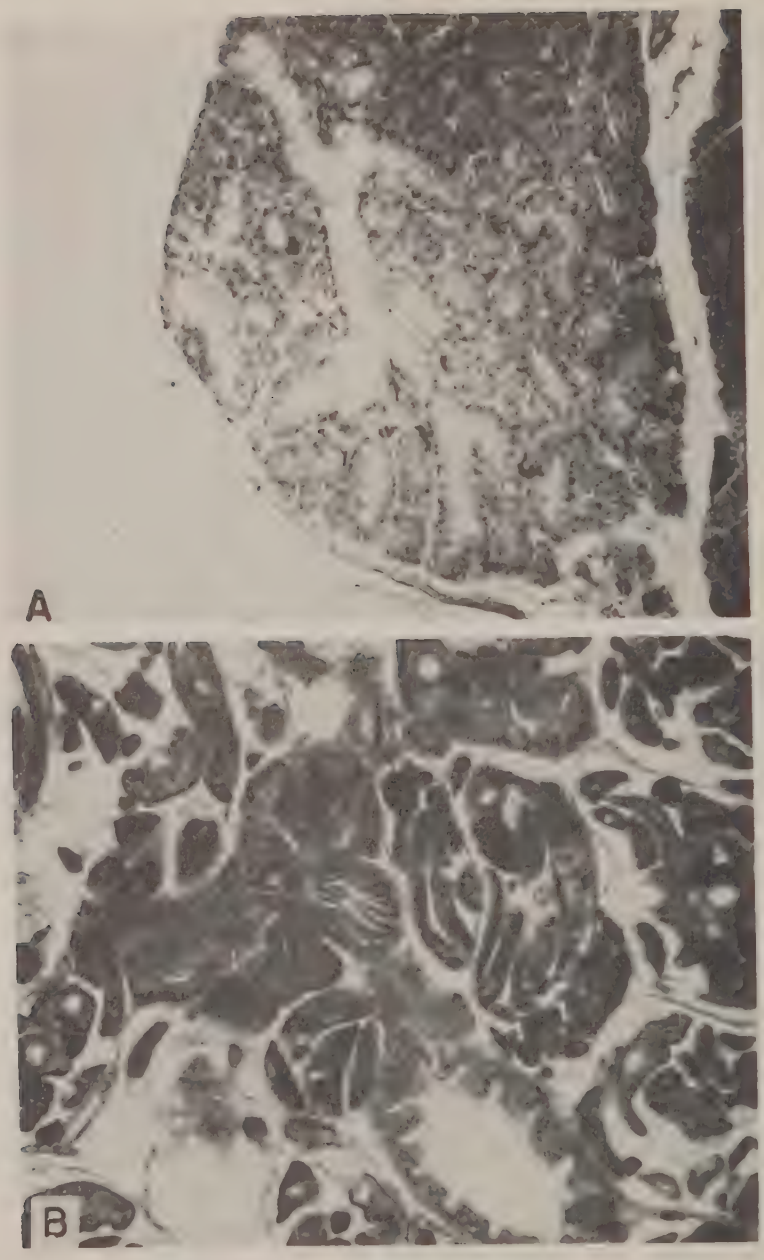

Fig. 3. Effect of Parorchis infection upon Thais liver. Bouin, Weigert's iron acid hematoxylin and eosin, transverse section, 7 u, ca. X 50. A. Uninfected liver. B. Infected liver. Note extensive displacement and compression of liver tissue by parasites, occluded lumina of liver tubules.

No worms were found until the 30th day after first feeding encysted metacercariae, when sexually mature worms were recovered from each of the birds. For three months after being fed encysted metacercariae, none of the birds exhibited any symptoms of illness. However, three months and eight days after being fed cysts, the herring gull died suddenly. Three days later, one of the ring-billed gulls died, apparently in the same manner. Post-mortem examination failed to reveal the cause of death in either case, but mature Parorchis adults were recovered from the cloaca of each bird. The other two infected ring-billed gulls have shown no symptoms of illness during the slightly more than four-months period of their infections, although they are now (July) somewhat less greedy at feeding time than they were when captured last January.

Drills:

This experiment was designed to determine whether (1) Parorchis infections could be induced in large numbers of Thais in outdoor tanks and (2) whether there is any relationship between the size of the drill and its susceptibility to infection.

The experiment was performed in two 10 by 20 foot concrete tanks. Running sea water, at a constant depth of about 4 inches (roughly 2 cubic meters of water), was supplied to each tank at the rate of approximately 2 gallons per minute, permitting a complete change of water in about $4\frac{1}{2}$ hours.

Into each tank a lot of 653 snails was introduced from the rocky shore of our laboratory island in Santa Rosa Sound. Each lot consisted of 408 small drills (15 to 35 mm long) and 245 large drills (45 to 60 mm long). These size ranges were chosen arbitrarily to facilitate recognition of each size class. During the 33 days of the experiment, no food was supplied to the drills.

Three ring-billed gulls and one herring gull, known to be infected with sexually mature Parorchis adults and discharging miracidia in their feces, were hung in hardware cloth cages from the walls of the experimental tank; a single ring-billed gull, known to be free of Parorchis infection, was placed similarly in the control tank. The droppings of the gulls fell freely and directly into the water in each tank. The birds were fed daily either frozen small pinfish (Lagodon rhomboides) or frozen chopped mullet (Mugil cephalus).

Repeated sampling of the drill population about our laboratory island over a period of several months has never revealed infected snails, suggesting that incidence of Parorchis infection in the population is very low, if not absent. The incidence in nearby Pensacola Bay, on the other hand, is slightly above 2%. Thus, it was decided that a sample of 5% of the total number of drills in each group (roughly 2.5 times the natural incidence in the bay) should be adequate

to reveal any induced infections. Accordingly, 33 drills (about equal numbers of large and small individuals) were removed from each group initially and on the 13th, 21st, and 33rd days of exposure to gull droppings. All snails without visible infections when the liver was examined under a dissecting microscope were fixed in Bouin's fixative (Allen's modification) and stained sections were examined with a compound microscope to detect light infections.

No infections were observed in the samples prior to the 21st day, when one small infected snail was found. On the 33rd day, 2 large and 2 small drills (about 12% of the sample) proved to be infected. All infections were light and stained sections contained only first generation rediae, indicating that these were bona fide experimental infections. Although the time required for the development of each larval stage is unknown, these observations indicate that an extended period is required.

It is difficult to explain satisfactorily the low incidence of infection in this experiment in which it appeared certain the experimental snails would be exposed to a high concentration of miracidia. One might speculate that these results were due to (a) resistant snails (see Hyman 1951, pp. 307-308), or death of most of the miracidia before they could penetrate snails (See Linton 1914, Rees 1940, pp. 379-381), or a combination of these causes. However, this experiment must be repeated under various conditions before a precise explanation can be given.

On the basis of this study we may conclude that (1) Parorchis infections were experimentally induced in Thais; (2) For some unexplained reason the rate of infection was low; and (3) There seemed to be no important difference in the susceptibility of large and small drills to infection with Parorchis.

Incidence of Natural Infections of Parorchis Acanthus in Thais

Although the survey of the natural incidence of infection in drills from oyster-producing areas of the Gulf Coast region begun in the fall of 1956 has not been completed, some preliminary data from 2050 drills can be reported at this time (Table 3). These drills were collected in Galveston Bay, Texas, from Mississippi Sound, at Biloxi and Gulfport, Mississippi, and in Pensacola and Apalachicola Bays, Florida. Only massive infections detected by dissection are reported.

During repeated sampling of the drill population of the Pensacola Bay area, some samples of a hundred or more drills contained no infected snails, while in other samples of comparable size from different locations up to 7% were infected. Samples from one point on the north shore of the bay, where large numbers of herring and ring-billed gulls roosted during the fall and winter, almost invariably

Table 3. Incidence of *Parorchis acanthus* infections in *Thais* from three oyster-producing areas.

Area	Snails		
	Number examined	Infected	
		Number	Per cent
Northwest Florida	1123	23	2.05
Mississippi	475	16	3.37
Texas	452	3	0.66
Totals	2050	42	2.05

contained infected drills, while another area on the south shore where few gulls were noted, sampled on four occasions from November 1956, to February 1957, yielded only one infected snail out of 196 examined.

Of several hundred drills collected from the rocky shore of our laboratory island in Santa Rosa Sound, none was infected. Only a comparatively few gulls frequented the laboratory area during the past fall and winter.

The large gull populations which build up during the fall and winter, although important, are not the only source of Parorchis infection in the Pensacola area, for willets, dowitchers, and water turkeys, reported by Penner (1957) to harbor the adult worm elsewhere in Florida, also occur here to some extent, and could constitute an additional source of infection.

Possible Use of P. Acanthus in Biological Control of the Oyster Drill

The serious drill predation existing in certain areas of the Gulf oyster fishery requires development and institution of effective drill-control measures.

Although the natural incidence of Parorchis infections in Thais is low, it is evident that it causes considerable damage to the individual drill. This experimental work demonstrates that Thais can be experimentally infected with P. acanthus. The percentage experimentally infected was low, but still higher than natural incidence. Further study to determine how the rate of infection may be increased to the extent necessary to utilize this parasite as a biological control agent is warranted by this initial success.

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Literature Cited

Butler, P. A. 1953. The Southern oyster drill. Proc. Natl. Shellfish. Assoc. 44: 67-75.

Butler, P. A. 1956. Unpublished data on the reproductive cycle of Thais haemastoma.

Cable, R. M. 1937. The resistance of the herring gull, Larus argentatus, to experimental infections of the trematode, Parorchis acanthus. Jour. Parasitol. 23(6): 559.

Clench, W. J. 1947. The genera Purpura and Thais in the Western Atlantic. Johnsonia 2(23): 61-91.

Hyman, L. H. 1951. The Invertebrates... Vol. II. 1st ed.; 2d imp. vii + 550 pp. N. Y., McGraw-Hill Book Co., Inc.

Lebour, M. V. 1907. Larval trematodes of the Northumberland Coast. Trans. Nat. Hist. Soc. Newcastle, N. S., 1: 437-454; 500-501.

Lebour, M. V. 1914. Some larval trematodes from Millport. Parasitology 7(1): 1-11.

Lebour, M. V., and R. Elmhirst. 1922. A contribution towards the life-history of Parorchis acanthus Nicoll, a trematode in the herring gull. Jour. Marine Biol. Assoc. United Kingdom, N. S., 12: 829-832.

Linton, E. 1914. Notes on a viviparous distome. Proc. Natl. Mus. 46: 551-555.

Linton, E. 1928. Notes on trematode parasites of birds. Proc. U. S. Natl. Mus. 73(1): 1-36, pls. 1-11.

Nicoll, W. 1906. Some new and little known trematodes. Annals and Mag. Nat. Hist., 7th Ser., 17(102): 517-527.

Nicoll, W. 1907. Parorchis acanthus, the type of a new genus of trematodes. Quart. Jour. Micros. Sci. 151: 345-355, Pl. 21.

Penner, L. R. 1957. Personal communication: letters dated 8 April and 11 May 1957.

Rees, G. 1937. The anatomy and encystment of Cercaria purpurae Lebour, 1911. Proc. Zool. Soc. London 107, Ser. B: 65-73, Pls. I-II.

Rees, G. 1939. Studies on the germ cell cycle of the digenetic trematode Parorchis acanthus Nicoll. Part I. Anatomy of the genitalia and gametogenesis in the adult. Parasitology 31(4): 417-433.

Rees, G. 1940. Studies on the germ cell cycle of the digenetic trematode Parorchis acanthus Nicoll. Part II. Structure of the miracidium and germinal development in the larval stages. Parasitology 32: 372-391.

Shechter, V. 1943. Two flatworms from the oyster-drilling snail, Thais floridana haysae Clench. J. Parasitol. 29(5): 362.

Stunkard, H. W., and R. M. Cable. 1932. The life history of Parorchis avitus (Linton), a trematode from the cloaca of the gull. Biol. Bull. 62(3): 328-338.

Stunkard, H. W., and C. R. Shaw. 1931. The effect of dilution of sea water on the activity and longevity of certain marine cercariae, with descriptions of two new species. Biol. Bull. 61(2): 242-271.

MARKING SHRIMP WITH BIOLOGICAL STAINS

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Marking Shrimp With Biological Stains

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THE U. S. FISH AND WILDLIFE SERVICE initiated tests in 1954 to find a more suitable method for marking shrimp, since mechanical tags had demonstrated severe limitations. As a result, Dawson (1957) reported notable success using biological stains as marking agents in three species of penaeid shrimp.

The use of stains for marking living organisms is not a new device or idea. Loosanoff (1937), Vernon (1937), Feder (1955), and others have reported success in staining various marine animals. Chapman (1957) reported successful use of a trypan blue and titanium dioxide mixture in marking juvenile steelhead, *Salmo gairdneri.* Slack (1955) used machine ink to mark crayfish. Menzel (1955) successfully stained white shrimp, *Penaeus setiferus,* with fast green, one of the stains used by Dawson. Racek (1955) found a method of staining penaeid prawns by immersion in Nile blue sulfate.

Dawson's work is of particular interest because of the stain longevity in living animals. Trypan red and trypan blue stains remained fast and recognizable for over two hundred days. This, and his report of relatively low mortality incident to staining, makes his technique a promising tool with which to study these commercially important crustaceans.

Dawson's work was confined to laboratory experimentation. The problem remained to adapt his technique for field use and to determine whether these stains would remain fast and recognizable under natural conditions. Biscayne Bay, Florida, was chosen as a site for releasing a sizable group of stained pink shrimp, *Penaeus duorarum,* into an operating fishery. The purposes of this initial field experiment were:

(1) To test the longevity of stains under natural conditions.
(2) To learn how rapidly shrimp could be stained and what equipment is necessary to stain shrimp in large quantities.
(3) To learn how readily stained shrimp would be recognized when recaptured in the fishery.
(4) To study the movement of stained shrimp within the Biscayne Bay area.

The Biscayne Bay Fishery

The waters of Biscayne Bay support a sizable bait fishery, with six to eleven boats operating under permits issued by the Florida State Board of Conservation. The shrimping is confined to a regulatory area (Figure 1) and sale of shrimp taken in this area is for bait purposes only. Higman (1952) and Siebenaler (1953) present a history of this fishery, which has been in operation since about 1952.

Prior to May 19, 1958, shrimp were taken in Biscayne Bay by otter trawls and rigid roller-frame trawls. After this date shrimping was restricted by the Florida State Board of Conservation to use of rigid roller-frame trawls only. Channel wing nets are legal and are occasionally used, but they are of minor importance in the bait fishery. Tabb (1958) summarizes the status of this fishery.

Equipment was designed which was portable and could be utilized for sub-

sequent staining experiments. Equipment included a wall tent which housed a staining table and two large plywood shrimp-holding boxes. The larger box, 6 by 2 by 3 feet deep, supplied with running sea water is capable of holding three to four thousand shrimp for staining over a period of six to eight hours. The smaller box, 2 by 4 by 2 feet deep, served as the receptacle for shrimp which had been stained and placed in a trough of running sea water built into the staining table.

A gasoline operated pump furnished sea water at sixteen gallons per minute to the boxes and staining table during the time staining was in progress. As needed, shrimp were dipped out of the large holding box and placed in 12 by 14 inch plastic inserts built into the staining table. Stained shrimp placed in the trough of running sea water flowed down and dropped into a live car. When the live car contained approximately 500 stained shrimp it was taken out and anchored a short distance off the beach ready for transporting to the release site six miles to the south in Biscayne Bay.

Stains and Minor Equipment

Fast green is considerably less toxic than the other three usable stains noted by Dawson and was chosen for the initial work on that basis. All shrimp were stained by injection with a 1 per cent solution of fast green[1], dissolved in artificial sea water (Subow 1931) containing only the essential inorganic salts. Tests indicated artificial sea water is a superior solvent to the filtered natural sea water used by Dawson (1957).

Tuberculin syringes, one quarter cc., half cc., and one cc., were tested throughout staining. The half cc. syringes are superior for this work. No. 27, quarter inch needles proved the most satisfactory of several gauges and lengths tested. Multi-dosage syringes proved of no practical value.

Speed of Staining

Twenty-one students and members of the regular staff of the University of Miami Marine Laboratory participated in the staining phase. We found that anyone without previous experience but with normal finger dexterity can stain 200 to 240 shrimp per hour.

The Staining Operation

Table 1 contains a summary of the staining operation. At the University of Miami Marine Laboratory, Virginia Key, a total of 20,080 individuals, mean carapace length 19.1 mm, were stained between April 24 and May 29, 1958. Shrimp were taken in Biscayne Bay in rigid roller-frame trawls the night before staining. High winds and inclement weather during the period kept bait shrimp boats ashore for periods of from three to nine days. Thus an operation which could have been accomplished in five to seven days covered a thirty-six day period.

Release of Stained Shrimp

Rounsefell and Kask (1943) stated that one-at-a-time releases "soon result in a ring of predators waiting to gobble up each fish." They recommend releases as a school unit—our experience demonstrated the wisdom of this

[1]The disodium salt of p,p′— dibenzyldiethyldiamino—p″—hydroxytriphenyl-carbinol trisulfonic acid anyhydride (manufacturer National Aniline Co.).

ıethod. Releases in units of 500 were made in thirteen different locations in iscayne Bay along a line from Matheson Hammock Beach to Southwest oint on Key Biscayne.

TABLE 1

SUMMARY OF BISCAYNE BAY SHRIMP MARKING

Shrimp Marked			*Shrimp Recovered*			
			[1]Verified		[1]Unverified	
Date	Number	Mortality in 6 hrs.	Date	Number	Date	Number
4/24	1100	43	5/1	1	5/6	2
4/28	1000	52	5/3	1	5/7	1
4/29	1500	61	5/9	1	5/11	3
4/30	2000	68	5/10	1	5/18	1
5/5	2380	81	5/19	1	5/22	4
5/13	1000	44	5/22	3	5/25	1
5/19	1000	31	5/23	4	6/2	7
5/21	2000	54	5/24	5	6/5	2
5/22	1000	43	5/25	1	6/8	1
5/26	1000	31	5/26	2	6/13	1
5/27	2000	62	5/27	6	6/15	9
5/28	1000	51	6/1	2	6/16	4
5/29	3100	101	6/6	5	6/18	6
			6/9	1	6/19	8
	20,080	722	6/10	2	6/20	1
			6/11	1		
			6/12	2	Total..	51
			6/14	6		
			6/15	2		
			6/16	2		
			6/17	2		
			6/21	1		
			6/29	4		
			7/5	1		
			Total....	57		

Movement of Stained Shrimp

Figure 1 summarizes movement of stained shrimp recovered by the bait ishery. It is of interest to note that nearly all of the movement was to the ıorth toward Bear Cut and the Dodge Islands. This movement agrees with the ımpression of bait fishermen that pink shrimp populations move out of nursery ıreas which are to the south, into the areas of grass. Probably as they reach a ıarger size, they move into the area of mud bottom and from there into the ɔcean through Bear Cut and Government Cut.

Analysis of shrimp recoveries required a knowledge of fishing effort with respect to the release site. Periodic observations of the nightly fishing and interviews of bait fishermen indicated fishing effort north and south of the release site was approximately equal.

[1]Verified recoveries include shrimp taken in the fishery, returned, and identified; unverified recoveries include reports by fishermen of stained shrimp noted, but not actually returned for verification.

Recovery of Marked Shrimp

Table 1 summarizes reports of stained shrimp recovered in Biscayne Bay. A total of 108 stained shrimp were reported taken by bait fishermen, 0.5 per cen of the 19,358 released alive. Fifty-seven of this number were verified by actua

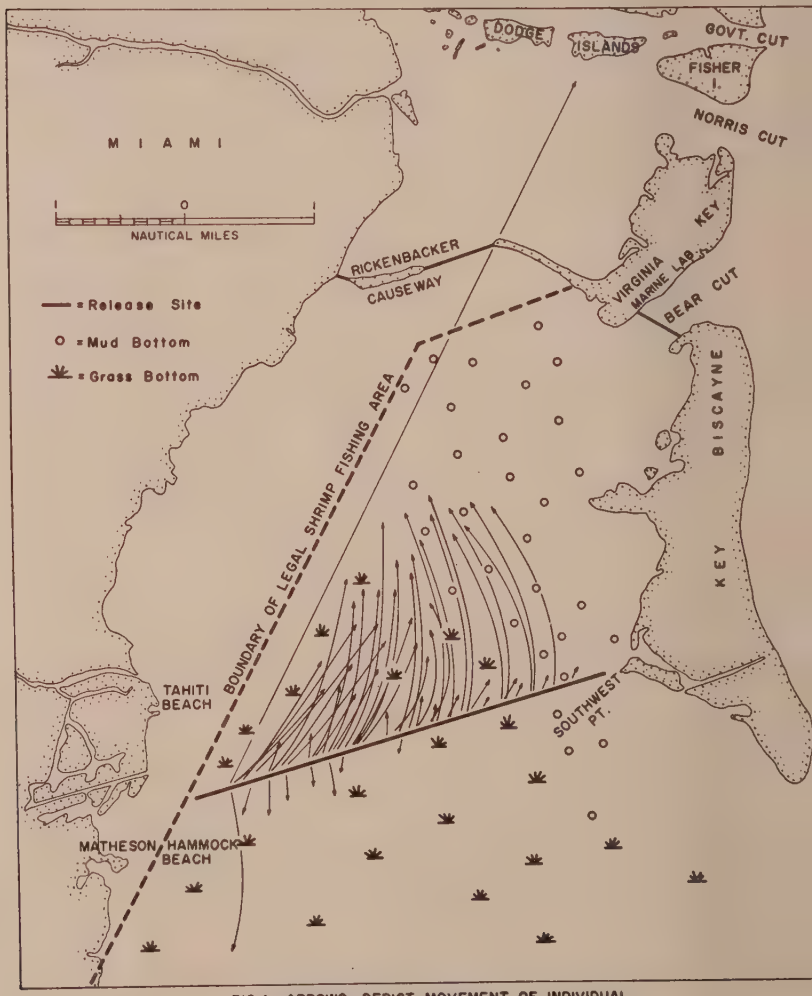

FIG. 1 ARROWS DEPICT MOVEMENT OF INDIVIDUAL SHRIMP FROM RELEASE SITE TO POINT OF RECAPTURE.

return of the stained animals. Several comments are pertinent here:

(1) Lack of personnel limited the coverage of landings in Biscayne Bay.

(2) All shrimp recovered, including the last five verified recoveries June 29 and July 5, remained clearly marked, with no detectable fading in the stained area.

(3) Because of the manner in which live shrimp for bait purposes are handled, it is difficult to note stained shrimp passing through a bait fishery. The live animals are handled rapidly in the early morning hours to insure delivery in good condition to retail bait houses.

(4) It was difficult to keep an active interest among bait fishermen for this project, yet we obtained reasonably good information on the actual point of capture for most verified recoveries.

(5) Biscayne Bay was closed to otter trawl fishing May 19 (rigid roller-frame shrimping continued as usual). This probably materially reduced the number of stained shrimp recoveries. Since there was clearly a general movement of shrimp northward in the Bay, shrimp with a long "out time" simply were unavailable when they reached the mud bottom area of the Bay where otter trawls had normally fished.

Conclusions

(1) Fast green can be used successfully to mark pink shrimp in a bait fishery.

(2) Stained animals were readily recognized but recovery requires more effort than would be needed for shrimp tagged with a mechanical device.

(3) Shrimp recovered with a maximum possible "out time" of 73 days and a minimum of 37 days showed no evidence of stain fading. It is reasonable to assume that this stain will be recognizable over a considerably longer period than has been demonstrated here.

(4) Large quantities of shrimp may be easily stained without prohibitive mortality by inexperienced personnel.

(5) General movement of shrimp in Biscayne Bay, Florida, for the period covered was north and northeastward toward outlets to the ocean.

(6) There is presently no commercial fishery for pink shrimp in areas contiguous to Biscayne Bay. Although some effort for recovery of stained shrimp was made in the lower Keys and Tortugas fishery, no stained shrimp from Biscayne Bay were recovered. This lends some evidence that Biscayne Bay populations are not subject to exploitation in their mature stages.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to students and members of the University of Miami Marine Laboratory staff for participation in the staining phase of this experiment. The author is also indebted to Mr. Robert Still of Miami for advice and help in handling shrimp preparatory to staining.

REFERENCES

Chapman, D. W.
1957. Use of latex injections to mark juvenile steelhead. Progr. Fish.-Cult. *19* (2): 95-96.

Dawson, C. E
1957. Studies on the marking of commercial shrimp with biological stains. Spec. sci. Rep. U.S. Fish Wildl. Serv.—Fisheries No. 231, 23 pp.

FEDER, H. M.
1955. The use of vital stains in marking Pacific coast starfish. Calif. Fish Game *41* (3): 245-246.

HIGMAN, J. B.
1952. Preliminary investigations of the live bait shrimp fishery of Florida Bay and the Keys. Fla. St. Bd. Conserv. Marine Lab., U. of Miami, (mimeo. rept.) 52-20. 8 pp.

LOOSANOFF, V. L.
1937. Use of Nile blue sulfate in marking starfish. Science *85* (2208): 412.

MENZEL, R.W.
1955. Marking of shrimp. Science *121* (3143): 446.

RACEK, A. A.
1955. Penaeid prawn fisheries of Australia with special reference to New South Wales. Indo-Pacific Fish. Council 6th Session, c 55/SYM 3. 18 pp

ROUNSEFELL, GEORGE A. AND J. L. KASK
1943. How to mark fish. Trans. Amer. Fish. Soc. *73*: 321-363.

SIEBENALER, J. B.
1953. The Biscayne Bay commercial fishery. State Board of Conservation. Marine Lab., U. of Miami. Tech. Ser. No. 6, 9 pp.

SLACK, KEITH W.
1955. An injection method for marking crayfish. Progr. Fish.-Cult. *17* (1): 36-38.

SUBOW, N. N.
1931. Oceanographic tables U.S.S.R. Oceanogr. Inst. Hydromet. Com. Moscow. 208 pp.

TABB, DURBIN C.
1958. Report on the bait shrimp fishery of Biscayne Bay, Miami, Florida. Fla. St. Bd. of Conserv., Marine Lab., U. of Miami, (mimeo. rep.).

VERNON, A. A.
1937. Starfish stains. Science *86* (2220): 64.

A Field Observation of Mortality of Marine Fish Larvae Due to Warming

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A Field Observation of Mortality of Marine Fish Larvae Due to Warming

Georges Bank, one of the most productive fishing grounds in the North Atlantic, provides a habitat for many populations of demersal fish, including cod, haddock, whiting, and several species of flounders. The non-tidal circulation pattern, being rotary, is favorable to maintaining these populations on the bank. However, there exists ample evidence that from time to time a considerable amount of Georges Bank water is carried off the southern part of the bank in the surface layer of the relatively warm slope water band (Bigelow 1929, Walford 1938). Although the mechanism of these movements is not fully understood, such a southerly drift could be caused by winds or by the absorption of coastal water by the large frictionally driven eddies that develop from time to time along the northern edge of the Gulf Stream (Iselin 1939). Iselin speculated that this warm slope water is unfavorable to large numbers of animals living near the edge of the continental shelf.

The North Atlantic Fishery Investigations of the U. S. Fish and Wildlife Service have conducted surveys of Georges Bank and the surrounding area in 1953, 1955, 1956, and 1957 in order to measure the relative abundance of fish eggs and larvae and to relate their distribution and mortality to hydrographic conditions. We have observed that a drift off the southeast edge of Georges Bank occurred in each of these years. Four 2-week cruises were made each year during February, March, April, and May. Operations included continuous Hardy Plankton Recorder hauls at the surface and at 10 meters, bathythermograph lowerings and surface salinity samples, drift bottle releases, and egg samples taken with a one-meter net for hatching and identification. The track of a typical cruise is shown in Figure 1. The drift of bottles, eggs, and larvae revealed that, in general, the water movement from the area of maximum spawning on Georges Bank was southerly.

One of the interesting features of the hydrography of the Georges Bank area is the band of relatively warm slope water along the southern edge of the bank. This slope water band is characterized by contrasting tongues of coastal and

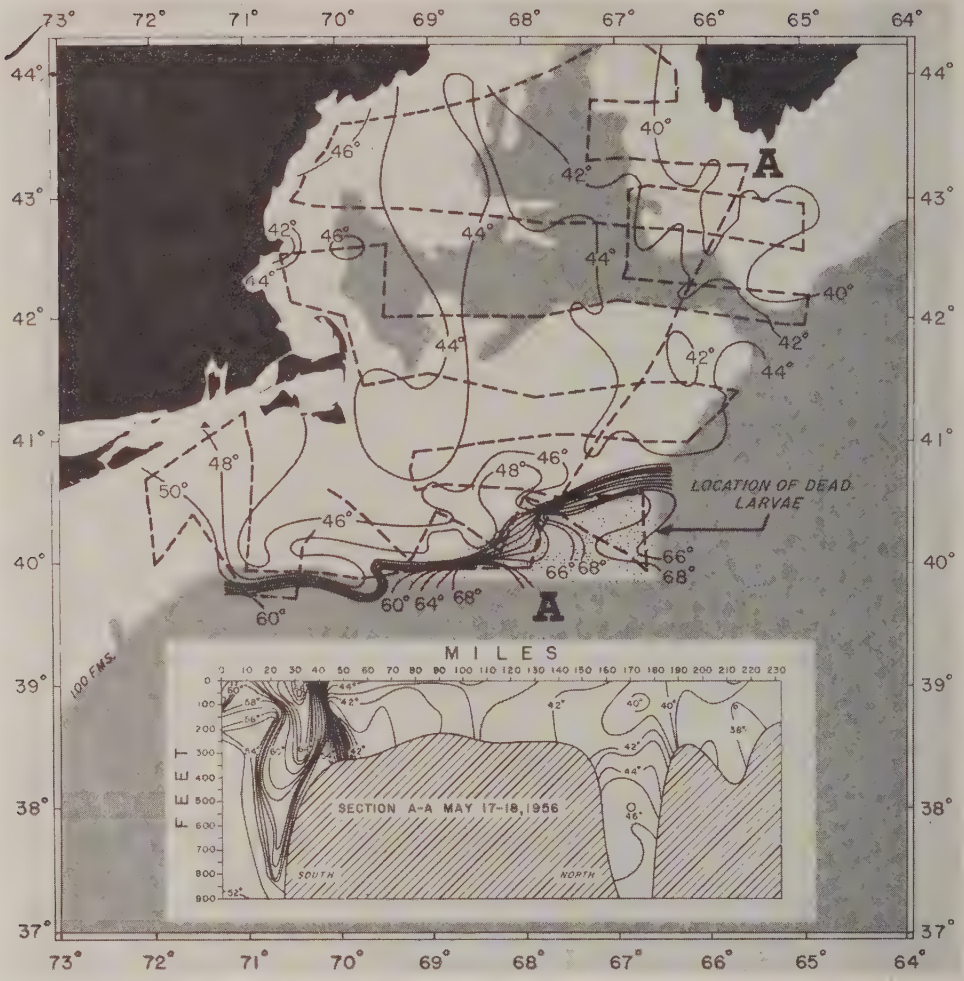

FIG. 1. Distribution of temperature and dead larvae, May 16–29, 1956.

Gulf Stream water. Here tropical plankton becomes mixed with coastal forms, and both drift slowly to the northeast, parallel to the Gulf Stream. In general, the northern boundary of this slope water band coincides with the 100-fathom contour line, but its position relative to Georges Bank, especially on the southeast part, varied during the 4 years of our surveys.

In May 1956 this slope water extended farther than usual over the southern edge of the bank (Fig. 1). Surface temperatures increased from 46°F to 68°F and surface salinities from 33‰ to 36‰ within a space of 10 miles. While we were cruising through this area, the temperature in our hatching jars (which are kept cool in a bath of running sea water) rose to 65°F, and most of the eggs died or aborted. No fish eggs, fish larvae, or invertebrates endemic to the Gulf of Maine-Georges Bank area were taken in the one-meter net surface hauls in this area, but juvenile stages of a number of tropical and oceanic species of fishes were caught, for example: mullett, *Mugil cephalus*; saurel, *Trachurus trachurus*; and lanternfish, *Myctophum humboltii*. The invertebrates in these samples were all tropical forms, the most numerous being the copepods, *Sapphirina gemma*, *Labidocera acutifrons*, *Undinula vulgaria*, and the euphausiid, *Euphausia krohnii*.

Later study of the Hardy Plankton Recorder gauzes revealed that certain sections contained many fish larvae in various stages of decomposition. These larvae were found in a particular area and only in the recorder towed at the 10-meter level. We first considered the possibility that there was a shortage of formalin in the storage tank of the recorder. However, only the

boreal forms were affected; all other plankters on the same sections were excellently preserved. This indicates that the affected larvae must have died some time before capture. The majority of these dead larvae were yellowtail flounder (*Limanda ferruginea*), but there were some whiting (*Merluccius bilinearis*) and a few larvae that appeared to be blennies.

We took the dead larvae only in the slope water (Fig. 1). Only boreal forms had died in this zone, while tropical and sub-tropical forms had not. The eggs and larvae of the species normally resident on Georges Bank, which were maintained in hatching jars, died during the time that the vessel was passing through the slope water. The only condition that changed during this time was temperature of the circulating sea water in which the hatching jars were immersed for cooling. The water inside the jars was the same as that in which the eggs had been originally collected, and thus only the temperature could have varied. These facts are all consistent with the conclusion that the eggs and larvae died as a consequence of temperature above their limit of tolerance.

Several observers have associated mass mortalities of adult fishes with abnormally low temperatures (Storey and Gudger 1936, Gunter 1941, Verrill 1901). Copenhagen (1935) described a periodic mortality of fish in the Walvis region associated with a marked increase in surface temperature. However, he concluded that death was due either to anoxia, hydrogen sulphide poisoning, or poisonous plankton. Wiborg (1948) noted the occurrence of large numbers of dead cod larvae in the Lofoten area in April 1930, but unfortunately no hydrographic observations were taken at the time. As far as we know, the present observations are the only ones that have been made which indicate a mortality of marine fish larvae as a result of warming.

Precise knowledge of the thermal requirements of the egg, developing embryo, and larval stages is meager.[1] A species of fish can exist only within a certain range of temperature. However, this range is more or less adjustable, the extreme limits being precisely set by conditioning (acclimation). In general, coldwater fishes have a narrower range of thermal tolerance than warmwater fishes. It appears also that marine species are more sensitive to temperature change than freshwater species, and that the thermal requirements of the very early stages are more exacting than that of the adult.

Carefully controlled laboratory experiments show that (1) the rate of temperature change is an important factor in mortalities, for it can outstrip the ability of the fish to acclimate to the change or move to a more favorable environment, (2) the upper lethal temperature is remarkably precise within species when repeated for fish from similar acclimation temperatures, and (3) the upper lethal temperature is closer to the acclimated temperature than is the lower lethal temperature.

Conditions on the southern edge of Georges Bank during May 1956 were such that Georges Bank larvae could be subjected to a sudden increase in temperature. The dead larvae averaged 2.5 mm in length, which approximates the hatching size of both yellowtail and whiting. Judging from the incubation rates of both yellowtail and whiting eggs and from the direction and rate of surface drift in the area, these larvae were probably hatched from eggs spawned approximately 25 miles north during the end of April. The temperature of the water mass in which the eggs and larvae drifted and to which they had been acclimated was approximately 44°F. The age of the larvae and their rate of drift indicate that they were subjected to a rise in temperature of over 20° in a period of probably less than 24 hours. At that planktonic stage of development, their swimming powers are much too feeble to enable them to move to a more favorable environment.

The above observations on flounder and whiting are very important, as the larvae of other and more important species such as haddock, cod, hake, and cusk may meet a similar fate. The extreme fluctuations in year-class strength of haddock, for instance, may be related to such a mortality in the larval stages. The drift of concentrations of haddock eggs and larvae has frequently been followed by us from the spawning centers on the northern edge to the southern edge of Georges Bank and then lost. For example, a large concentration of haddock larvae situated just north of the warmwater area in May 1956 had disappeared by June. It now appears that the reason we have not found larvae in the slope water zone before is that they had died in the warm water, and their bodies had disintegrated or sunk below the depth sampled.

This is further evidence to support the theory that larval fish swept off the southern edge of Georges Bank into the slope water zone are lost to the fishery.

[1] For a summary of work done on the thermal requirements of fishes, see Brett (1956).

REFERENCES

Bigelow, H. G. 1929. Plankton of the offshore waters of the Gulf of Maine. Bull. U. S. Bur. Fish., **40**(2): 1–509.

Brett, J. R. 1956. Some principles in the thermal requirements of fishes. Quart. Rev. Biol., **31**(2): 75–87.

Copenhagen, W. J. 1953. The periodic mortality of fish within the Walvis region. A phenomenon within the Benguela Current. Invest. Rep. Fish. Mar. Biol. Surv. S. Africa, No. **14**: 1–35.

Gunter, G. P. 1941. Death of fishes due to cold on the Texas Coast, January 1940. Ecology, **22**: 203–208.

Iselin, C. O.'D. 1939. Some physical factors which may influence the productivity of New England's coastal waters. J. Mar. Res., **2**(1): 74–85.

Storey, M., and E. W. Gudger. 1936. Mortality of fishes due to cold at Sanibel Island, Florida, 1886–1936. Ecology, **17**: 640–643.

Verrill, A. E. 1901. A remarkable instance of the death of fishes at Bermuda in 1901. Amer. J. Sci. Ser. 4, **12**: 88–95.

Walford, L. A. 1938. Effects of currents on the distribution and survival of eggs and larvae of haddock (*Melanogrammus aeglefinus*) on Georges Bank. Bull. U. S. Bur. Fish., **49**(29): 1–73.

Wiborg, K. F. 1948. Investigations on cod larvae in the coastal waters of northern Norway. Fiskeridir. Skr. Havundersøk., **9**(3): 1–26.

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DIET-INDUCED VARIATION IN THE FREE AMINO ACID COMPLEX OF *SARDINOPS CAERULEA*

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Diet-Induced Variation in the Free Amino Acid Complex of *Sardinops caerulea*

By

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STUDENTS of animal ecology, population dynamics, and resource management have long been faced with the problem of describing the size and integrity of the populations with which they are working. This general problem is often confused, on the one hand, by the fact that morphological differences may only be a reflection of environmental differences and not of genetic differences and, on the other hand, by the fact that genetic differences are not always reflected morphologically. Until recently, physiological and genetic laboratory techniques have been quite limited in their applicability to field problems. By the use of paper partition chromatography as a tool in biochemical analysis, it may be possible to resolve some of the differences arising between the strictly field and laboratory approaches (BUZZATI-TRAVERSO and RECHNITZER, 1953). I chose free amino acid analysis since much of the previous work had been done with this determination. In order to determine the applicability and limitations of free amino acid analysis as an aid in systematics, the following experiment was performed.

Methods

In the spring of 1954 Steinhart Aquarium received approximately 1500 sardines (RADOVICH, 1954). These fish were taken in Hipolita Bay, Baja California, and are believed to be representative of a single population.

Four tanks were made available by the California Academy of Sciences for the experiments. Each was approximately 4 feet by 2 feet and 3 feet deep, and contained about 160 gallons of water. The tanks were made of leached redwood. Sand-filtered sea water was continuously cycled through the tanks. Throughout the course of the experiment the water temperature ranged from 66° to 71°F., with a maximum daily range of $\pm 0{\cdot}5$°F.

The four tanks (C_1, C_2, P_1, P_2) were each stocked with 25 sardines. These fish were withdrawn from the main stock tanks without conscious selection.

[1]) Published by permission of the Director, U. S. Fish and Wildlife Service.

An additional sample of 25 sardines was sacrificed at the start of the experiment and is designated as "Control". These fish were in a starved or semi-starved condition. Fish in tanks C_1 and C_2 were fed on a high carbohydrate diet. Fish in tanks P_1 and P_2 were fed on a high protein diet. The fish were fed on a ration of 4 g. (dry weight) of food per fish per day. The ration was divided into a morning and afternoon feeding.

The carbohydrate diet consisted of tapioca dyed red to simulate brine shrimp (upon which sardines will feed in captivity). This diet contained less than 0·0025 g. of amino acid per gramme of food as determined by acid hydrolysis (SKINNER *et al.*, 1940) and ninhydrin colour test (LEDERER and LEDERER, 1953). The tapioca was about 90% carbohydrate. The protein diet consisted of fish meal, chicken eggs, vitamin supplement, and fish liver oil. This material was homogenized and fed as dry pellets. On acid hydrolysis it yielded the following amino acids:— aspartic acid, glutamic acid, glycine, threonine, alanine, tyrosine, tryptophan, proline, leucine, valine, lysine, and serine, as determined by paper partition chromatography (BRIMLEY and BARRETT, 1954). This diet was 56·94% protein and 7·08% carbohydrate.

The experimental fish were maintained on these diets for a period of six weeks and then sacrificed. Their weights and lengths were recorded, and body cavity fat was noted. A chromatogram was made of a sample of the pectoral muscle.

The muscle sample (approximately 1 mm^3.) was squashed $4\frac{3}{4}''$ diagonally from the corner of a sheet of Whatman 1 filter paper ($22\frac{3}{4}'' \times 18\frac{1}{2}''$) and allowed to dry. The excess flesh was scraped off after about fifteen minutes and the spot was dry in about thirty minutes. I believe that the amount of autolysis taking place in this short period was negligible. The component free amino acids were separated by two-dimensional descending chromatography. The first solvent was phenol/water, 454 g./170 ml. This mixture was allowed to operate for 34 hours. The chromatograms were then dried before the second run was started. The second solvent was allowed to act for 20 hours. It consisted of propionic acid/water, 224 ml./176 ml. mixed with butanol/water, 375 ml./24 ml. in a ratio of 1:1 (BENSON *et al.*, 1950). In order to develop the colour, a 0·5% ninhydrin solution in water-saturated butanol and 5% collidine was sprayed on dry chromatograms and heated for 5 minutes at 100°C. Two chromatograms were made from each fish. If a given amino acid spot appeared on either sheet it was counted as present in the fish.

Analysis of Chromatograms

The free "pool" amino acids which were identified in the pectoral muscle were:— aspartic acid, glutamic acid, glycine, threonine, alanine, tyrosine, tryptophan, and phenylalanine. Lysine, proline, serine, and valine analysis are unreliable because of the difficulties in resolving these in this solvent system. Of the eight clearly distinguishable acids, aspartic acid and alanine were chosen as the two representative amino acids to be examined in fish muscle because of their known high metabolic activity and their clear delineation on the chromatograms. Both of these primary amination products have reflected dietary change very well.

Since only the presence or absence of the acid was recorded, the number of

Table 1

Proportion of fish showing aspartic acid by K-class intervals and tests of significance

K	(X) Number of fish showing aspartic acid	($N-X$) Number of fish not showing aspartic acid	(N) Total number of fish	$\hat{P}$ Proportion showing aspartic acid
71–90	8	3	11	·7273
91–110	12	27	39	·3077
111–170	5	28	33	·1515
Total	25	58	83	

A:
$$P = \frac{20}{50} = \cdot 400$$

$$\frac{(\cdot 7273 - \cdot 0455) - (\cdot 3077 - \cdot 0128)}{\sqrt{\frac{(\cdot 400)\ (\cdot 600)}{(39)\ (11)} \quad 50}} = 2 \cdot 313 > K_{.01}$$

B:
$$P = \frac{17}{72} = \cdot 2361$$

$$\frac{\cdot 2949 - (\cdot 1515 - \cdot 01515)}{\sqrt{\frac{(\cdot 2361)\ (\cdot 7639)\ (72)}{(39)\ (33)}}} - 1 \cdot 579 > K_{.06}$$

Accept H_{ALT}: $P_{k1} > P_{k2} > P_{k3}$ at 10% level

fish (X) showing the acid takes on a binomial distribution with parameter P. An estimate ($\hat{P}$) of the parameter P is given by $\hat{P} = X/N$ where X is the number of successes (i.e., the number of fish showing the acid) and N is the total number of fish examined. The statistic $\hat{P}$ has an asymptotic normal distribution with mean P and variance $\frac{P(1-P)}{N}$.

It is assumed in this paper that the approximation of the sampling distribution of the sample proportion to the normal distribution holds sufficiently well to provide the basis for tests of significance. The small size of condition group k_1 (70–90) casts some doubt upon the validity of this assumption, and the conclusions drawn from the tests of significance. If we follow the lead of Clark (1928), a subjective estimate of condition is given by the condition factor K, where K is equal to the weight in grammes multiplied by 10^{-7} and divided by the length in millimetres cubed. K was computed for each fish and the fish were then grouped according to K value. $\hat{P}$ was computed for each K-group (Tables 1 and 2).

Since it is desired to know whether there is an inverse relation between conditions and pooling of aspartic acid and/or alanine, we may test the null hypothesis $Pk_1 = Pk_2 = Pk_3$ against the alternative hypothesis that $Pk_1 > Pk_2 > Pk_3$; $k_1 < k_2 < k_3$. Condition groups k_1, k_2 are first compared for a difference in the proportion of fish showing acid and then condition groups k_2, k_3 are compared by the method described by Eisenhart, Hastay, and Wallis (1947). The null hypothesis may be rejected at the $\alpha/2$ level if the tests of significance applied to the pairs of groups may be rejected at the α level.

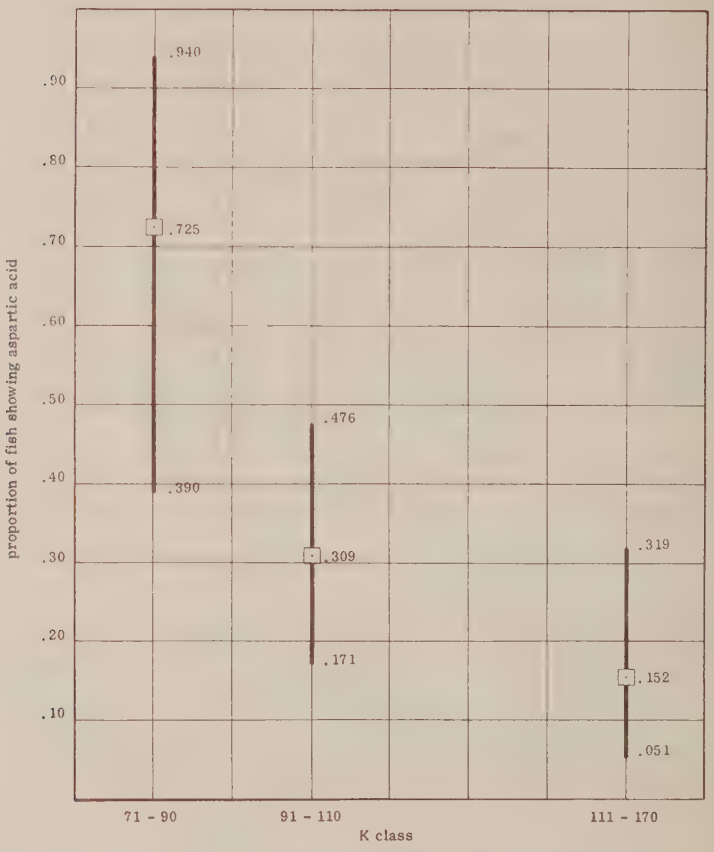

Figure 1. Proportion of fish showing aspartic acid by *K*-class intervals with 95% confidence limits.

The null hypothesis may be rejected at the 10% level for aspartic acid and at the 5% level for alanine.

The proportion of fish, by *K*-class intervals, showing aspartic acid is given in Table 1. In Figure 1, I have plotted $\hat{P}$ against *K* values. About each estimate of *P*, I have constructed 95% confidence limits. These limits were calculated from tables in FISHER and YATES (1949).

The proportion of fish, by *K*-class intervals, showing alanine is given in Table 2. Figure 2 was prepared in the same manner as Figure 1. Both figures show the same result — as the *K* values decrease, the proportion of fish showing the free amino acid increases.

In the next set of analyses, I wished to test the hypothesis that there was a homogeneous distribution of the free amino acid among the various diet groups. This is best accomplished by using analysis of contingency tables (DIXON and MASSEY, 1951). Since my numbers are small, I had to use a correc-

Table 2

Proportion of fish showing alanine acid by K-class intervals and tests of significance

K	(X) Number of fish showing alanine acid	$(N-X)$ Number of fish not showing alanine acid	(N) Total number of fish	$\hat{P}$ Proportion showing alanine acid
71–90	9	2	11	·8182
91–110	19	20	39	·4872
111–170	6	27	33	·1818
Total	34	49	83	

A:

$$P = \frac{28}{50} = \cdot 560$$

$$\frac{(\cdot 8182 - \frac{1}{22}) - (\cdot 4872 - \frac{1}{78})}{\sqrt{\frac{(\cdot 5600)\ (\cdot 4400)\ 50}{429}}} = 1 \cdot 760 > K_{.04}$$

B:

$$P = \frac{25}{72} = \cdot 3472$$

$$\frac{(\cdot 4744) - (\cdot 1818 - \cdot 0152)}{\sqrt{\frac{(\cdot 3472)\ (\cdot 6528)\ 72}{128 \cdot 7}}} = 2 \cdot 734 > K_{.01}$$

Accept H_{ALT}: $P_{k1} > P_{k2} > P_{k3}$ at 5% level

tion due to continuity. These procedures estimate the differences from a calculated distribution which is based on the given distribution. These differences, which are additive, are then compared with a χ^2 table. If the calculated differences exceed those of the table, we conclude that homogeneity does not exist. The analysis of contingency tables for aspartic acid is presented in Table 3. At the 5% level of significance the protein and the carbohydrate groups cannot be shown to be the same with respect to aspartic acid. Nor can the protein and control groups be shown to be the same. The carbohydrate and control groups were the same with respect to aspartic acid at the 5% level.

Table 4 shows the differences in proportion of fish containing alanine with respect to diet group. At the 5% level of significance the protein group does not differ from the carbohydrate group. The carbohydrate group cannot be shown to be the same as the control group. Nor can the protein group be shown to be the same as the control group at the 5% level.

From the above data it is apparent that the magnitude of difference is sufficiently great to obviate the need for quantitative determinations. Since rigorous randomization procedures were not used, bias may have crept in. I believe, however, that the principle of randomization has not been seriously violated.

Fish fed on the protein diet all had fat in the body cavity. Some of the carbohydrate-fed fish had fat in the body cavity. None of the control fish had fat in the body cavity.

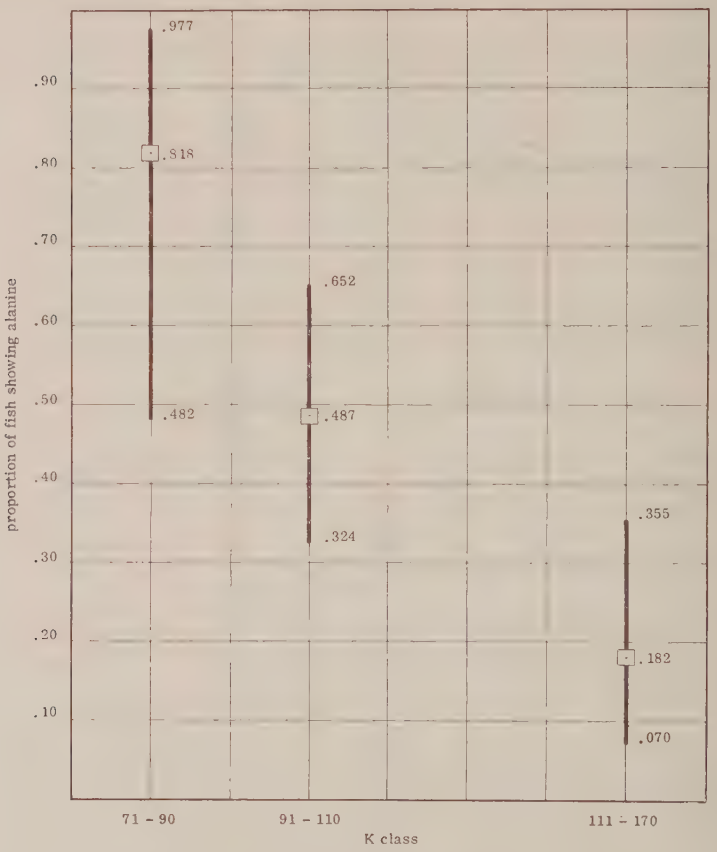

Figure 2. Proportion of fish showing alanine by *K*-class intervals with 95% confidence limits.

Discussion

As I have stated previously, these fish are believed to be representative of a single population. They were all two years old, as determined by counting scale annuli. CLARK (1928) has tabulated *K* values for a large number of San Pedro sardines. From her data, I have concluded that the normal *K* for the range of lengths in which I was working must lie between 105 and 110. At the start of the experiment the mean *K* value for these fish was below that of the San Pedro fish and their subsequent weight-length relationship suggested a shift in metabolic processes (FARRIS, 1956). Further evidence of the metabolic shift is gained from the above examination of the distribution of aspartic acid and alanine in the population.

The data of PHILLIPS *et al.* (1952) suggested that in brook and rainbow trout a shift in the efficiency of nitrogen metabolism occurs in the first week of starvation. The rate of nitrogen loss becomes progressively less as the week

Table 3

Analysis of contingency tables, with a correction due to continuity, for proportionate distribution of aspartic acid with respect to diet

Diet	Number of fish showing aspartic acid	Number of fish showing no aspartic acid	Total
Carbohydrate	11	20	31
Protein.....	3	26	29
Total	14	46	60

$\sqrt{X^2_c} = 1{\cdot}995$ Refer to Table VIII of Fisher & Yates

$m = \frac{14 \times 29}{60} = 6{\cdot}77$ Significant ·05

$p = \frac{6{\cdot}77}{14} = {\cdot}4836$

$$X^2_c = \left(\frac{[(11)\ (26) - (20)\ (3)] - 30}{(31)\ (29) \cdot (14)\ (46)}\right)^2 60 = 3{\cdot}9812 > X^2_{(.05)}$$

Carbohydrate	11	20	31
Control	11	12	23
Total	22	32	54

$$X^2_c = \left(\frac{[(11)\ (12) - (20)\ (11)] - 27}{(22)\ (32)\ (31)\ (23)}\right)^2 54 = 0{\cdot}4010 < X^2_{(.05)}$$

Protein.....	3	26	29
Control	11	12	23
Total	14	38	52

$$X^2_c = \left(\frac{[(3)\ (12) - (26)\ (11)] - 26}{(14)\ (38)\ (29)\ (23)}\right)^2 52 = 7{\cdot}353 > X^2_{(.05)}$$

progresses. In a later paper, Phillips *et al.* (1953) described an initial period of rapid weight loss followed by a period of comparatively little weight loss. Toward the end of the fourteenth week of the starvation period, the rate of weight loss rose rapidly, as did the mortality rate. This suggests to me a change in the metabolic process during the final stages of starvation. The initial change in rate of weight loss very likely is a change in the efficiency of substrate utilization, but the final rate change quite possibly is a shift in metabolic processes.

If it is true that the genome prescribes the range and limits of the enzyme complex, then the range and limits of the metabolic products are just as surely determined. Within this range, however, the effects of the internal and external environment and the effect of enzyme substrate may manifest themselves in many ways. I should like to suggest the following alternative pathways for the appearance of aspartic acid and alanine in the free amino acid pool. One source may be excessive protein breakdown and/or lack of de-amination or

Table 4

Analysis of contingency tables with correction due to continuity for proportionate distribution of alanine with respect to diet

Diet	Number of fish showing alanine	Number of fish showing no alanine	Total
Carbohydrate	6	25	31
Protein	3	26	29
Total	9	51	60

$$X^2_c = \left(\frac{[(6)\ (26) - (25)\ (3)] - 30}{(9)\ (51)\ (31)\ (29)}\right)^2 60 = \cdot 3782 < X^2_{(\cdot 05)}$$

Carbohydrate	6	25	31
Control	25	0	25
Total	31	25	56

$$X^2_c = \left(\frac{[(6)\ (0) - (25)^2]}{(31)^2\ (25)^2}\right)^2 56 = 36{\cdot}42 > X^2_{(\cdot 05)}$$

Protein	3	26	29
Control	25	0	25
Total	28	26	54

$$X^2_c = \left(\frac{[(3)\ (0) - (25)\ (26)]^2}{(28)\ (26)\ (29)\ (25)}\right)^2 54 = 43{\cdot}23 > X^2_{(\cdot 05)}$$

other enzymatic diversions. Interruption of de-amination could be brought about by lack of de-aminase enzyme synthesis. Or, perhaps, aspartic acid and alanine are no longer synthesized, the amino nitrogen travelling by an alternative pathway. Since asparagine was not identified on the chromatogram, I infer that this compound does not participate in this phenomenon. Further experiments are necessary to choose the correct interpretation from among these possibilities.

To return to the major argument that the investigation of free amino acid pools may be used as a systematic tool, the data indicate that at least two components of the "pool" vary with the environment. It has been shown that an inverse relationship exists between the proportion of fish showing alanine and aspartic acid and starved condition of the fish. While this experiment has demonstrated the variability of two components of the free amino acid "pool" which was caused by the environment, it has not defined its parameters. The dynamic nature of muscle tissue introduces a degree of variability which requires a high degree of precision in order to define. Refinement of the techniques already described may be sufficient in order to resolve the problem. On the other hand, a more stable tissue may be found, or perhaps an examination of fats and carbohydrates will reveal relationships heterofore unsuspected. When the total biochemistry of the organism is revealed, we should be able to characterize that organism at any phylogenic level we may desire.

Summary

1. The free amino acid content of pectoral muscle tissue of the California sardine (*Sardinops caerulea*) was compared by paper partition chromatography for lots of 25 fish fed on different diets. The diet history of these fish was (1) starved or semi-starved (one lot), (2) protein diet (two lots), and (3) carbohydrate diet (two lots).

2. Twelve amino acids were found, including aspartic acid, glutamic acid, glycine, threonine, alanine, tyrosine, tryptophan, phenyl alanine, lysine, proline, serine, and valine. The variability of only two, aspartic acid and alanine, was examined.

3. The proportion of fish having free aspartic acid and alanine varied inversely with the condition (*K*) of the fish.

4. The proportion of fish having free aspartic acid was greatly reduced in the protein-fed fish. The proportion did not differ between the control fish and carbohydrate-fed fish.

5. The proportion of fish having free alanine was much greater in the control fish. The proportion did not differ between the carbohydrate-fed fish and the protein-fed fish.

6. Possible explanations for these observed differences are given.

7. Further work is necessary before paper chromatography of free amino acids can be used without reservation as a systematic tool for distinguishing groups of less than specific rank.

8. Some areas for further work are suggested which may resolve some of the difficulty associated with this problem.

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The assistance of Mr. Harold Hass, Tropic Waters Aquarium, has been extremely valuable in the preparation of the diets. Mr. Anatole Loukashkin, California Academy of Sciences, fed the fish. Mr. John MacGregor, U.S. Fish and Wildlife Service, made all the measurements on these fish. I also wish to thank Dr. R. C. Miller and Dr. Earl S. Herald, California Academy of Sciences, for making the facilities of Steinhart Aquarium available to me. Special thanks are due Dr. Raymond Barrett, Dartmouth College, whose aid and encouragement during the formulation of this problem were indispensable. The comments of Dr. E. L. Tatum, Stanford University, concerning the interpretation of results have likewise proved of great help. I am indebted to Mr. Bruce Taft, U.S. Fish and Wildlife Service, for the preparation of the statistical material.

Literature

Benson, A. A., J. A. Bassham, M. Calvin, T. C. Goodaie, V. A. Hass, & W. Stepka, 1950. "The path of carbon in photosynthesis. V. Paper chromatography and radio autography of the products". J. American Chem. Soc., **72**: 1710–18.

Brimley, R. C., & F. C. Barrett, 1954. "Practical Chromatography". pp. 1–128. Chapman & Hall, Ltd., Chatham.

Buzzati-Traverso, A. A., & A. Rechnitzer, 1953. "Paper partition chromatography in taxonomic studies". Science, **117**: 58.

Clark, Frances N., 1928. "The length-weight relationship of the California sardine (*Sardina caerulea*) at San Pedro". California Div. Fish and Game, Bull., **12**: 1–59.

DIXON, Wilfred J., & Frank J. MASSEY, Jr., 1951. "Introduction to Statistical Analysis". McGraw-Hill, New York and London.

EISENHART, C., M. W. HASTAY, & W. A. WALLIS, 1947. "Techniques of Statistical Analysis". McGraw-Hill, New York and London.

FARRIS, D. A., 1956. "Diet induced differences in the weight-length relationship of aquarium fed sardines (*Sardinops caerulea*)". J. Fish. Res. Bd. Canada, **13** (4): 507–13.

FISHER, R. A., & F. YATES, 1949. "Statistical Tables for Biological, Agricultural, and Medical Research". Haftner, New York.

LEDERER, E., & M. LEDERER, 1953. "Chromatography, a Review of Principles and Applications". Elsevier Publishing Company, New York.

PHILLIPS, A. M., F. E. LOVELACE, D. R. BROCKWAY, & G. C. BALZER, 1952. "The nutrition of trout". N.Y. Conserv. Dept., Albany, N.Y.

PHILLIPS, A. M., F. E. LOVELACE, D. R. BROCKWAY, & G. C. BALZER, 1953. "The nutrition of trout". N.Y. Conserv. Dept., Albany, N.Y.

RADOVICH, J., 1954. "The use of a blanket net in sampling fish populations". California Fish and Game, **40**: 353–65.

SKINNER, W. W. (Editor), 1940. "Official and tentative methods of the association of official agricultural chemists". Ass. Off. Agric. Chem., Washington, D.C., pp. 1–757.

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A Decade of Progress in Fishery Biology of the Gulf and Caribbean Area

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THE OFFICERS of your organization asked me to discuss at your opening session the progress made during the past decade in the studies of biological problems pertaining to the fisheries of the Gulf and Caribbean area. I am very happy to address this meeting today because the Gulf and Caribbean Fisheries Institute, inaugurated in 1948, was a major factor in this progress. In his welcoming speech, Dr. F. G. Walton Smith, the chairman of the inaugural session said: ". . . The Institute . . . seeks to bring together first of all fishermen, the fish dealers, the fish processors; secondly, the fishery biologists, technologists and economists; and thirdly, the conservation administrators of the fisheries. In this manner it is believed that the several groups of persons . . . may have an opportunity of broadening their horizons and of seeing their problems in a truer perspective against the background of fisheries as a whole." Those of us who have followed the growth and activities of the Institute have no doubt that this particular aim, outlined by its originator, has been fulfilled. The Institute has provided the means of understanding and communication between the specialists and laymen. This contact is frequently lost because of the rapid progress of scientific knowledge, the usage of new terminology, and the peculiarities of scientific thinking which are not always comprehensible to the general public.

The second meeting of the Institute, held here in Miami in 1949, inaugurated a project of summarizing the knowledge regarding the Gulf of Mexico. Thanks to splendid cooperation of many members of the Institute and of affiliated organizations, this project was completed and resulted in the publication in 1954, by the Fish and Wildlife Service, of a book entitled, "Gulf of Mexico, Its Origin, Waters and Marine Life." Information contained in this book makes a convenient stepping stone for making an appraisal of the progress attained during the intervening years.

Let us consider first what conditions are essential for success of any research project and let us determine whether they are present in the Gulf area. Fishery biology is a branch of applied science which combines several disciplines, including oceanography, geology, zoology, botany, mathematical statistics, physiology, ecology, biochemistry and technology. Fishery investigations cannot be conducted in the quietness of a laboratory away from the sea. They require shore installations, adequate floating equipment and trained personnel capable and willing to spend many days at sea. There are now several places along the

Gulf coast and in Cuba where facilities for marine research are available. It is true that only some of these institutions have at their disposal funds and vessels large enough to extend scientific operation to a considerable distance from home ports. Others are primarily engaged either in teaching or in research dealing with local problems. Progress of scientific research depends on the availability of well trained scientists, interested in fishery biology as a scientific career. This human material is being provided by several local institutions affiliated with the colleges and universities of the Gulf area. The ever increasing number of students receiving training in The Marine Laboratory of the University of Miami and in other scientific establishments along the Gulf coast, constitutes the cadre of scientists for the expanding research program.

Shore laboratories, adequate floating equipment, and sufficient funds are naturally the prerequisite conditions for the progress of scientific research; they do not constitute, however, a creative force which stimulates scientific thinking and brings about the solution of a scientific problem. Originality of thought among the young scientists should be encouraged at every step of scientific thinking and more time should be devoted to theoretical considerations underlying research problems and to critical definitions of specific research problems. There is always a danger that the neglect in theoretical thinking and in formulation of a research problem may lead to repetitious and wasteful accumulation of observations. High academic standards maintained by principal educational institutions of the Gulf area constitute a guarantee that this is not the case.

It is obvious, of course, that sufficient background information is needed before an attempt is made to outline a more complex analytical study. The last ten years of research yielded abundant results pertaining to living resources of the Gulf. The following are probably the most spectacular results. Exploratory fisheries operations conducted by the Fish and Wildlife Service research vessel *Oregon* by using various types of gear in depth from 10 to 250 fathoms yielded 630 species of fish, of which number 10 species were new. Among the crustacea two new genera and sixteen new species of decapods and three new species of stomatopods were described and the collection of various mollusks provided interesting facts about their distribution. It is clear from the results of this work that our knowledge of Gulf fauna is incomplete, even with reference to the important species of fish and Cephalopods.

Knowledge of the life history of a commercial species of fish or shellfish constitutes a basis for formulating sound management of the resource. Studies of black mullet, *Mugil cephalus,* in Florida conducted by C. P. Idyll and J. W. Sutton of The Marine Laboratory of the University of Miami, have demonstrated that in each area of the Florida coast the fishery is largely dependent on its own stock, that fishing has a considerable effect on the local population of fish, and that east coast, west coast and northwest coast populations are biologically different from one another and therefore should be treated as distinct groups as far as regulation of fishery is concerned.

The migration of the giant bluefin tuna and related species was the object of studies of the Miami Laboratory, Woods Hole Oceanographic Institution, the Laboratory in Bimini and other organizations. Marked hooks were used for tagging and interesting observations on migration of this fish as they moved north from the Florida Straits to Nova Scotia were made from airplanes. Study

of the biology of these fishes is by no means complete, but a better understanding of their movements and spawning habits has been attained.

New data to the life history of the sailfish, *Istiophorus americanus,* in Florida waters, together with the observation on spawning habits and methods of feeding, have been added independently by J. W. Gehringer of the U. S. Fish and Wildlife Service and by Gilbert L. Voss of the Miami Laboratory. The fish was found to be extraordinarily fertile, the gonads yielding from 2.3 to 4.6 million eggs.

With reference to purely estuarine fishery, the seasonal movements and growth of the Atlantic croaker, *Micropogon undulatus,* in Lake Pontchartrain were studied by R. D. Suttkus of the Zoology Department of Tulane University. Although this species contributes only about 600,000 pounds of meat annually or less than one quarter of one per cent of total fish production in the Gulf and eastern Florida, the fishery is quite important for local communities on the shores of Lake Pontchartrain.

Detailed ecological study of the fishes in the vicinity of Cedar Key, Florida, made by George K. Reid of A. & M. College of Texas, added considerably to the knowledge of speciation, biology, movements, and feeding habits of 122 species of local fishes. This type of work is a desirable continuation of ecological studies of Gulf fishes initiated in 1938 by G. Gunter.

Among the many studies of invertebrate populations of the Gulf, mention should be made of the monographic treatment of the taxonomy of *Cephalopoda* by G. L. Voss. This study has increased the list of known species of these mollusks in the Gulf from 26 to 42 and added one new genus and four new species. It is of interest to note that only less than 10 per cent of the species recorded are endemic, the remaining being either circumtropical warm water forms or those of North Atlantic origin. This conclusion is of interest from the point of view of zoogeography, especially if one compares the Gulf Cephalopod fauna with that of the Mediterranean which has been noted for the number of endemic species.

Our knowledge of the distribution and ecology of marine borers of the family *Limnoridae* (*Isopoda*) in North and Central America was much augmented by comprehensive treatment of the subject by R. J. Menzies of the Lamont Geological Observatory. Studies of the biology and physiology of shipworms, *Teredo, Bankia* and *Phyloteredo,* made in The Miami Marine Laboratory provided scientific foundation for the development of control measures. Practical implication of this type of study is self-evident.

It is a well established fact that shrimp populations make regular inshore and offshore migrations and that estuaries along the coast of the Gulf are the nursing grounds where juvenile shrimp feed and grow before setting their course to the open sea. The full importance of the estuarine period of life and the dependence of shrimp on certain types of food is not, however, fully understood. Likewise, further ecological studies are needed to determine the effects of competition of shrimp with noncommercial animals and the effects of biological associations between shrimp and other animals during their estuarine and oceanic periods of life. The work conducted during the past decade was primarily of exploratory nature; successful attempts were made in locating new shrimp grounds and in determining the size of stock available to the fishery. In the course of these investigations a new resource consisting of

royal red shrimp, *Hymenopenaeus robustus,* was discovered by the Gulf Fisheries Exploration and Gear Unit of the U. S. Fish and Wildlife Service at Pascagoula. This red shrimp provides a new, tasty variety to the existing shrimp industry. It is worth mentioning here also a theoretical study made by James B. Higman of the University of Miami Marine Laboratory, of the behavior of pink groove shrimp, *Penaeus duorarum,* in electrical field. The experiments showed that interrupted direct current caused the shrimp to move toward the anode. At present the findings have no practical application because power requirements are too large, but the experimentations along this line are of value because of the possibility of using electric currents in directing the movements of shrimp toward traps or nets.

Spiny lobster fishery is of great importance to the Caribbean area. Success of the fishery is much dependent on a knowledge of the behavior and movements of the crustacean. This information was obtained by tagging experiments conducted by C. P. Idyll and Charles Dawson of the Miami Laboratory. It was found that adult *Panulirus* migrates along the shores of the coast of Florida, covering the distances varying from a few to almost a hundred miles. Development of the lobster was studied by John B. Lewis of Miami, who gave detailed description of the eleven developmental stages and found that pelagic lobster larvae, *Phyllosoma,* drift northward from the tip of Florida and are dispersed in the open ocean by the prevailing currents.

A new chapter in the study of plankton has been written by Dr. Hilary B. Moore and his associates at Miami in the analytical studies of the zooplankton of the Florida Current and the determination of the physical factors which control its vertical distribution. John B. Lewis made a study of standing crop and of the environmental conditions affecting zooplankton, 40 miles east of Miami. His observations disclosed small seasonal changes, marked diurnal migrations and extreme deficiency of water both in the inorganic phosphorus and inorganic nitrogen.

Shellfishery research of general interest was concerned primarily with the studies of *Dermacystidium,* which is claimed to cause widespread epizootic in the Gulf and South Atlantic waters. Valuable contributions about the pathology and life history of this fungus-like parasite of oyster made by Sewell Hopkins, Sam Ray and others, greatly advanced our knowledge about the disease affecting a large percentage of oyster population in southern waters.

Sponges from the eastern part of the Gulf of Mexico were identified, and some of them redescribed by the foremost authority on this group M. W. de Laubenfels. The list indicates 52 species, of which 11 species are new.

For some strange reason, marine fungi have failed to attract the attention of microbiologists. Very little is known about this important group of organisms capable of producing specific and highly potent chemicals. This gap has been partially filled by the work of S. Meyers on the marine fungi of Biscayne Bay and by observations of T. W. Johnson on the development of common brackish water species, *Leptosphaeria discors.*

Local surveys of the Cedar Key area, Tampa Bay and Biscayne Bay, conducted by the Miami Laboratory, provided better understanding of the ecological conditions in these areas. The data are most useful for the management of local living resources and for the control of pollution.

The problem of the Red Tide is of paramount importance to coastal communities of the Gulf States. Practical consideration demands that some effective

method of controlling the disastrous outbreaks of blooming caused by *Gymnodinium* and associated organisms be found and applied to prevent the spreading of red water. On the other hand, it is doubtful that a satisfactory method of control can be formulated without an understanding of the basic conditions which cause the overproduction of *Gymnodinium* and other toxic microorganisms. Federal, state and private organizations continued to work on this problem, which fundamentally is the problem of oceanic productivity. The organism responsible for the outbreak was identified and cultured. Oceanographic conditions preceding the outbreak were studied and attempts were made to correlate the Red Tide phenomenon with the pattern of movements of coastal waters, with the phosphorus and nitrogen contents of sea water, with the composition and abundance of plankton preceding the outbreaks, etc. Several theories and hypotheses were advanced, but the problem of Red Tide is still far from being solved. Time does not permit me to discuss in any detail the present status of these studies.

An interesting suggestion regarding the conditions which may stimulate the Red Tide was made by H. T. Odum, J. B. Lackey, I. Hynes and N. Marshall in a joint investigation sponsored by the University of Florida and Duke University. On the basis of the data accumulated during the outbreak of Red Tide of 1952 to 1954, the authors attached significance to the differences in the N/P ratios in various harbors and bays and suggested that "there is a possibility that the increasing multiple pollution of the shallow coastal estuaries and land drainage may be producing a higher incidence of the Red Tide phenomenon than might otherwise occur." It is clear that Red Tide is a very complex phenomenon, in which several environmental factors combine to produce a sudden outbreak It appears to me that the key to the solution of the problem, and therefore to the practical method of controlling it, lies in the studies of the growth requirements of Red Tide organisms, of their associations with other microorganisms, and in the biochemistry of the toxin.

Industrial and sewage pollution of harbors and bays continued to be a public menace threatening both health of human population and the existence of coastal living resources. Surveys made during the past ten years by public health authorities showed that for some time the Galveston Bay and the Mobile Bay were grossly polluted and that shellfish from these areas became unfit for human consumption. Extensive pollution of Biscayne Bay has been also demonstrated by the survey conducted by the Miami Laboratory. Only enlightened public opinion may stop this willful destruction of our water bottoms and shores. Methods of combating pollution are too well known and require no special scientific studies. It can be added, however, that two additional sources of pollution threaten our inshore waters—namely, the ever increasing amount of detergents which find their way into natural waters and the disposal of radioactive wastes. Biologists and state conservation officials should be on guard of this new danger.

As it is apparent from my brief review of scientific achievements in fishery biology, the work carried on during the past decade dealt primarily with fact finding, description of the existing resources and in operational studies.

Scientific research of the Gulf biological problems has not yet advanced far enough to give an explanation of the many peculiarities of the Gulf. One of the intriguing questions regarding the biology of the Gulf is concerned with the low productivity of its fishery resources, which at present yield annually only about

one-quarter of a million pounds of fish meat. What are the reasons for such low production? At present no adequate explanation can be advanced. It is known, however, that the central and deep portion of the western part of the Gulf is almost barren in comparison with the eastern part. Hydrographic studies carried on by A & M Texas Foundation show the existence of a hydrographic barrier which separates the surface waters of the Gulf into two distinct parts. How this hydrographic peculiarity affects the abundance of fish life of the Gulf area is not known. The more productive areas of the Gulf are found at the Campeche Bank on the south, at several red snapper banks in the northwestern part and on the broad shelf extending along the west coast of Florida. It is reasonable to assume that the movement of water masses contribute the primary factor determining the productivity of the various parts of the Gulf, but it is a challenge to fishery biologists of today and tomorrow to determine the nature of interaction of various factors and their combined effects on productivity.

Science cannot progress without the means of communicating its findings to other scientists and laymen. The Gulf area is lucky that the establishment of the "Bulletin of Marine Science of the Gulf and Caribbean" provides this outlet for publication of scientific findings and theories. Likewise, a series of popular pamphlets issued by the Miami Laboratory, the publication of the "Proceedings of the Gulf and Caribbean Fisheries Institute" and the attractive issues of the "Sea Frontiers," issued by the International Oceanographic Foundation, fulfill the essential task of keeping the general public informed about the goals and achievements of scientific research. Institutions sponsoring these publications and the officers engaged in writing, editing, and publishing these journals deserve our deep thanks. Their unselfish efforts are dedicated to the idea of promoting human welfare through conservation and better utilization of living resources of the ocean. I wish to express my appreciation for their valuable efforts and achievements.

OBSERVATIONS ON MUSCLE ATTACHMENTS, CILIARY MOTION AND THE PALLIAL ORGAN OF OYSTERS

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OBSERVATIONS ON MUSCLE ATTACHEMENTS, CILIARY MOTION, AND THE PALLIAL ORGAN OF OYSTERS

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A detailed study of the anatomy and functions of the oyster which I have conducted during past years has revealed several facts which heretofore have remained unnoticed. The present discussion deals with the adductor muscle, the skeleton and muscular apparatus of the gills, the ciliary tracts of the mantle and gills, and the structure of the so-called pallial organ.

Attachment of Adductor Muscle

The adductor muscle of all pelecypods is a very conspicuous and powerful organ. Experiments which I described at the 1952 meeting of the Association show that the muscle of a fully grown Crassostrea virginica withstands a pulling force up to 22 pounds (10 kilograms). Under this force the muscle fibers usually break in the middle and the remaining parts still adhere to the valves. Only rarely is the muscle separated at the place of attachment. On the other hand, by applying heat to the outside of the shell over the area of the muscle scar the connection between the muscle and the valve may be severed or at least greatly weakened.

The muscle scar is always smooth and glossy. Examination of sections made across the decalcified shell with the muscle attached to it show that the fibers end in a layer of epithelial cells next to the inner surface of each valve (Figure 1). The boundaries of these cells are not visible and the entire layer has the appearance of a syncytium. The nuclei are very large. Fibrillar protoplasmic strands extend across this layer and end at the inner surface of the shell. In the areas adjacent to the adductor muscle the mantle is covered with a typical epithelium which gradually changes into a specialized layer as the mantle approaches the adductor muscle. Brück (1913) who described this epithelium in Anodonta and Cyclas called it "adhesive" epithelium and considered that it provides a mechanism for attachment of muscle fibers to the shell. He did not notice, however, an organic film, no more than 2 microns in thickness, by which the muscle fibers are cemented to the shell of Crassostrea virginica. This film is always present in the oyster but is usually destroyed when muscles are cut from the shell. The cement by which muscles are attached to the shell probably consists of collagen, a protein generally found in connective tissue. To varify this assumption various connective tissue stains were used. The staining reactions were not too reliable, however, and better results were obtained by observing effects of proteolytic enzymes.

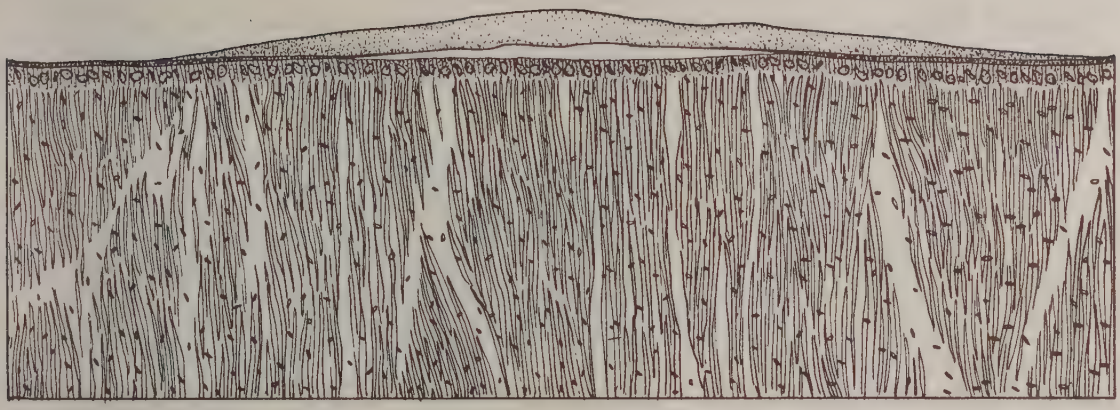

Fig. 1. Attachment of adductor muscle to shell. A thin layer of cement, in one place detached from the muscle, lies over a row of epithelial cells through which pass muscular fibrillae. Drawing from decalcified preparation of oyster shell with muscle attached. Hematoxylin and eosin--X 650.

It is known that under proper conditions collagen may be digested by an enzyme called collagenase. A series of experiments conducted last month at Woods Hole indicates that this protein plays a major role in the attachment of muscles in oysters. The experiments consisted of injecting small amounts of phosphate buffer solution containing 1 mg of collagenase per ml into the adductor muscles through small holes drilled in the valves. In another set of experiments the muscles of small oysters with the shells attached to them were immersed in the solution of collagenase and were kept at a temperature of 24-25°C. for 24-48 hours. Solutions of trypsin and of phosphate buffer without enzyme were used for control experiments. In all cases muscles treated with collagenase became detached within 36 hours, but controls remained attached to shells. There is no doubt that the oyster uses collagen as a cement for the attachment of its adductor muscle.

Gill Apparatus and Ciliary Motion

The muscle fibers of the gills present a different picture. They end in root-like processes which are deeply embedded in chitinous material. There is no sign of any cement by which they may be glued to the skeletal bars. The framework of an oyster gill is an inverted V-shaped structure with two sets of muscles. One set is located between the two converging arms of the frame; the contraction of these muscles brings the arms together and closes the gills. The other set of muscles located on the outside of the frame surrounds the sharp point where the arms are joined together. The contraction of these muscles pulls the arms apart and opens the gill. In this way access of water to the gill lamellae is facilitated. The opening and closing of the gill lamellae is one of the essential mechanisms by which the oyster regulates the rate of pumping of water through the gills.

Control of size of ostia is another mechanism which the oyster uses to regulate passage of water through the gills. The importance of ostia in feeding and respiration was correctly emphasized by T. C. Nelson (1940). Observing live oysters with the gills exposed on one side, I found that muscular contraction of the gills closes the ostia and that this method of regulating the dimensions of the ostia is much more important than filling and emptying of blood vessels of the gill filaments. The latter view has been maintained by Elsey (1935) but was not confirmed by my observations.

The lateral cilia which surround the ostia force the water into the water tubes and at the same time sort the particles suspended in water by throwing the large ones back to the surface of the filaments and by permitting the smaller ones to be drawn inside the gills. It is generally considered that the removal of particles from water is the function of the latero-frontal cilia. My observations show that this removal is incomplete and that the lateral cilia constitute another barrier which prevents the larger particles from passing through the ostia. In order to study ciliary currents the gills were

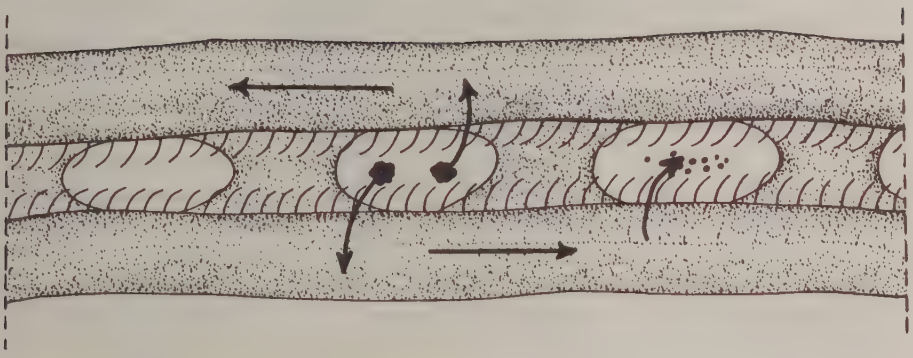

Fig. 2. Small portion of exposed surface of gill with expanded ostia. Horizontal arrows indicate direction of metachronic waves of the two rows of lateral cilia. Small particles of carbon (right) are sucked in while large particles (left) are thrown off by the recovery strokes of the cilia. Drawn from life--X 250.

exposed by removing parts of the shells, and phosphorescent powder (observed in ultraviolet light) or a suspension of colloidal carbon was added to the water. The behavior of the lateral cilia was recorded by the artist. It was clearly seen that while minute particles were sucked into the water tubes through the ostia, the larger ones were thrown back by the recovery strokes of the lateral cilia. In several instances the larger lumps of powder were tossed back and forth for a long time until they finally were discarded (Figure 2).

The control of ciliary motion is a problem of great physiological interest. Since the ciliary motion continues after the severance of the tissue from nerve ganglia, it is generally considered that ciliary activity is not under control of the nervous system although the possibility of such control was suggested by Lucas (1929, 1935) and others. I found that in the oyster with exposed gills, but otherwise intact, the motion of the frontal cilia and of the cilia of the terminal grooves of the gills ceases with the spontaneous contraction of the adductor muscle and is restored when the muscle relaxes. There is undoubtedly some sort of connection between muscular contraction and ciliary motion, but whether this control is exercised through the nervous system or by stimulation of the protoplasm of ciliated cells cannot be answered without a detailed physiological study. Electric shock applied directly to the ciliated epithelium produced no effect on ciliary rhythm.

The Pallial Organ

The pallial or abdominal organ of Crassostrea virginica is an inconpicuous little protuberance on the side of the adductor muscle in the right suprabranchial chamber. The surface of the organ is covered by long cells with still cilia (Figure 3). Numerous sensory cells with long processes are found compressed between the epithelial cells. Typical connective tissue underlies the epithelium. The large nerve with numerous branches ending at the periphery of the organ suggests that the pallial organ is of great importance to the oyster. The location of the organ inside the superbranchial chamber makes study of its physiology difficult (Figure 4). The organ probably serves for detection of mechanical disturbances in the water--a view which was advanced by several investigators who described this structure in various lamellibranches, (Dahmen 1923, Awati and Rao 1931). It does not seem reasonable that the organ is concerned with chemical sense. The location of the organ in the suprabranchial chamber speaks against this possibility. Furthermore, it is a well established fact (Hopkins 1932) that the edge of the mantle, with tentacles which come in contact with water before it enters the mantle cavity, is very sensitive to irritating or poisonous substances and gives the oyster a warning signal to close the shell. The long stiff cilia for the pallial organ seem to be more suitable for detecting mechanical disturbances than for responding to chemical stimulation.

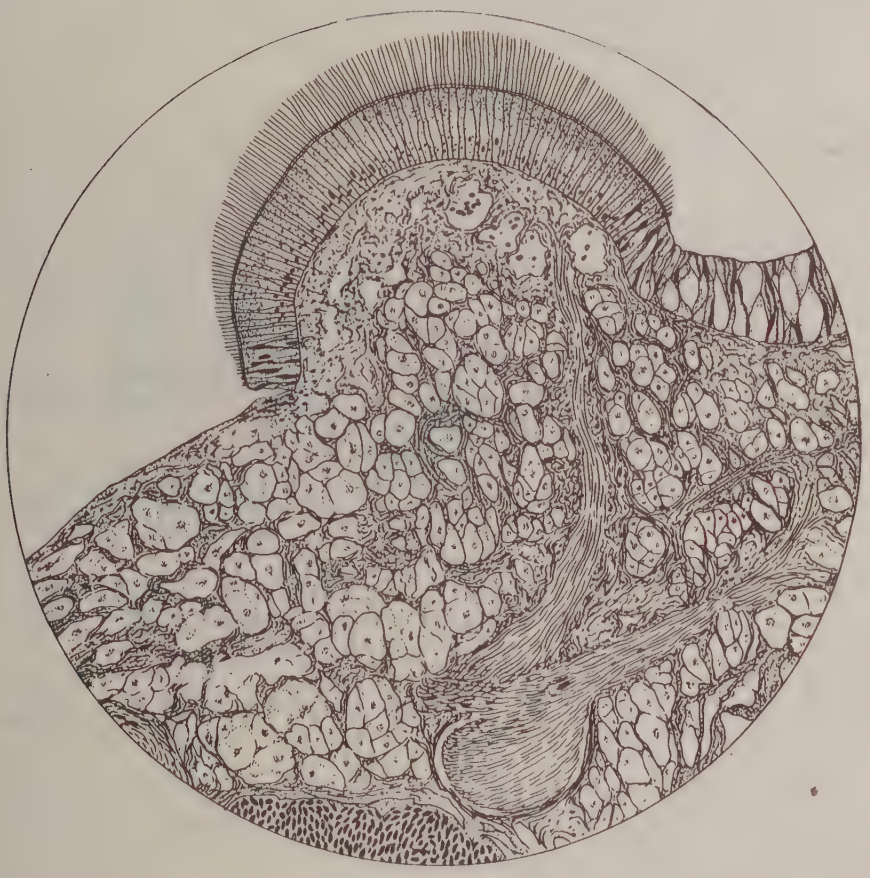

Fig. 3. Cross section of pallial organ showing long epithelial cells, narrow sensory cells on right and left sides of protuberance, and very large nerve trunk in connective tissues under the organ-- X 100.

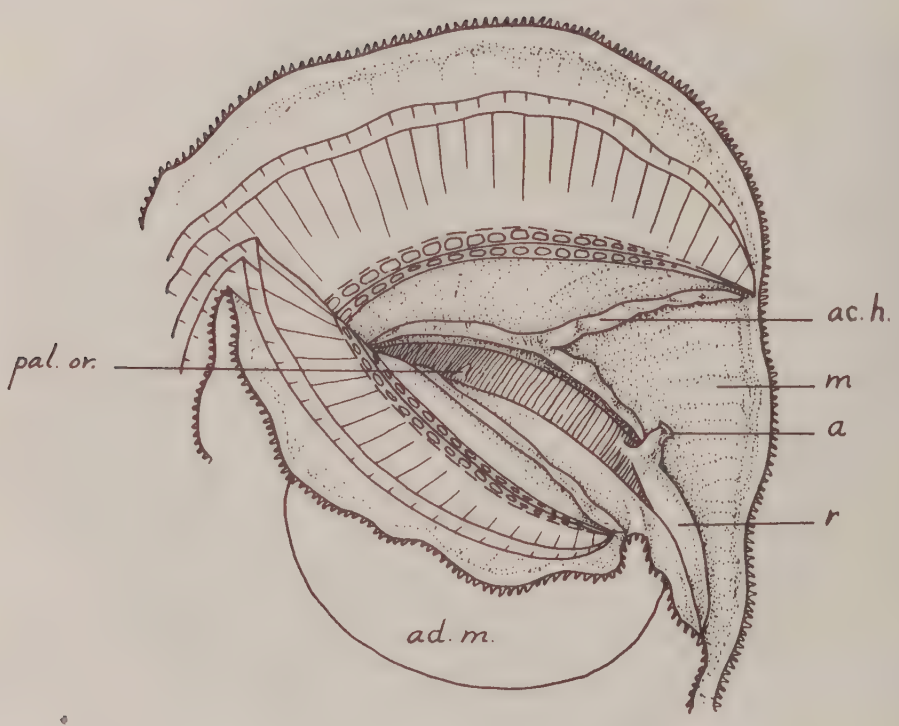

Fig. 4. Location of pallial organ (pal or) on wall of adductor muscle (ad m) in suprabranchial chamber which was cut and the opposing sides of mantle pulled apart. Accessory heart (ac h), mantle (m), and rectum (r). Drawn from life.

The observed details are of minor nature but they provide better understanding of the operation of the feeding and respiratory organs. Such an understanding is essential for the solution of practical problems of self-purification, feeding, and fattening of shellfish. The aim of these investigations is to learn more about the life of the mollusk in order to find ways of producing better oysters.

References

Awati, P. R., and H. S. Rao. 1931. Ostrea cucullata (the Bombay oyster). Ind. Zool. Mus. Lucknow 3: 1-107.

Brück, A. 1914. Die Muskulatur von Anodonta cellensis Schröt. Ein Beitrag zur Anatomie and Histologie der Muskelfasern. Zeitschr. wiss. Zool. 110: 481-619.

Dahmen, P. 1923. Anatomie von Ostrea chilensis Philippi. Jena. Zeitschr. f. Naturwiss. 52: 573-626.

Elsey, C. R. 1935. On the structure and function of the mantle and gill of Ostrea gigas and O. lurida. Trans. Roy. Soc. Canada, Sec. 5: 131-158.

Hopkins, A. E. 1932. Chemical stimulation by salts in the oyster, Ostrea virginica. Jour. Exp. Zool. 61: 13-28.

Lucas, A. M. 1929. The distribution of the branchial nerve in Mytilus edulis and its relation to the problem of nervous control of ciliary activity. Anat. Rec. 44: 230.

Lucas, A. M. 1931. An investigation of the nervous system as a possible factor in the regulation of ciliary activity of the lamellibranch gill. Jour. Morph. and Physiol. 51: 147-194.

Nelson, T. C. 1940. On the nature and action of diantlin a new hormone-like substance carried by the spermatozoa of the oyster. Jour. Exp. Zool. 85: 299-338.

THE PAST AND FUTURE OF OYSTER RESEARCH

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I wish to express my thanks to the officers of your organization for the invitation to address your opening session. This invitation gives me an opportunity to present some of the ideas which have developed in my mind during the 3-1/2 decades of my participation in oyster research in this country. As the title of my address indicates, I intend to speak of the past and future of oyster research. The omission of the present is deliberate because I am certain that all the members of this convention are fully aware of the current developments and achievements in oyster biology. Only occasionally, I shall refer to current research in relation to my discussion of future trends.

The beginning of the study of the oyster is shrouded in ancient history. We all know that oyster culture was practiced many thousands of years ago and that the oyster culturists of ancient times succeeded in developing the fundamental techniques of oyster farming which are used now. The Middle Ages hardly contributed anything worthwhile to the progress of zoology. The development of natural sciences during the Renaissance and the following period brought to light several problems in mollusk anatomy and physiology which are vitally important today. One example may suffice. In 1686 Anton de Heide described a gelatinous structure found in the stomachs of mussels and other shellfish. He called it "stylus cristallinus", a name retained ever since. Heide hazarded two guesses: that the crystalline style has something to do with reproduction, and that the structure is involved in the process of digestion. How prophetic was the latter surmise!

For more than two centuries the strange worm-like structure continued to puzzle biologists until in 1900 Coupin in France and Mitra in England, working independently, showed that the style is a protein rod saturated with digestive enzyme. During the intervening period at least seven different groups of theories were advanced to explain the nature and function of the style. The story of the style is given in detail by T. C. Nelson in his paper of 1918 in which he discusses the significance of this organ in lamellibranch physiology. This valuable contribution contains also the proof that the crystalline style is rotated inside its sac and in this mechanical way expedites the separation of food from sand in the stomach, while the dissolving style digests carbohydrates.

The last quarter of the 19th Century was the time of rapid advances in invertebrate anatomy and embryology. As a part of this general progress many facts regarding the structure of oysters and related mollusks were reported. At the beginning of the present century biologists began to pay more attention to life histories and mode of living of creatures of the sea. Aquatic biology, a new branch of science, was born and investigators began to emphasize the relationship between organism and environment, a new trend which found its full expression in modern ecological studies.

I want to limit my discussion today to the main phases of oyster research carried on in this country and abroad during the 30 years from 1921 to 1951. I know, of course, that breaking the continuity of historical events is arbitrary, but my reason for selecting this particular period is two-fold. First, during this time oyster research rapidly expanded and produced thousands of technical and popular papers. The second reason is a personal one. My association with oyster investigations in this country began in the twenties and has continued without interruption until the present. I believe, therefore, that I am in a position to add a little color to my technical presentation.

In 1921, when I joined the U. S. Bureau of Fisheries, the post of the Commissioner of Fisheries was occupied by Dr. Hugh Smith, a man of extraordinary scientific ability and broad intellectual interests. He was an inspiration to the young members of the Bureau and his collecting trips to the waters of Cape Cod, which he made regularly during the summers he spent at Woods Hole, gave us an opportunity to acquire a wealth of information about the local fishes and their habits. In his office he seemed to be reserved and rather formal. But we soon realized that under this appearance was a human heart of great kindness and understanding. An M. D. by education, he forsook the medical profession for ichthyology and became a world authority on fishes.

The position of Deputy Commissioner of Fisheries was occupied by Dr. Henry Frank Moore, whose name is familiar to many of us attending this convention. Dr. Moore's extensive work on the biology of oysters, his surveys of oyster grounds in Texas and Louisiana, and his penetrating study of the problems related to oyster feeding and oyster culture form a chapter in oyster studies of this period. Many investigations conducted after he finished his work started from the point where Dr. Moore left them. I specifically refer to his method of collecting the material discarded by the oyster and his quantitative studies of the food and feeding habits of this mollusk. The application of Moore's technique made it possible for Dr. Thurlow Nelson to develop the method for accurate determination of the amount of water filtered through the oyster gills. This technique has greatly advanced our knowledge of the physiology of the oyster.

In the early twenties scientific circles in the United States showed very little interest in marine sciences in general. Persons trained in this discipline were scarce. No courses in oceanography and fishery biology were given at any college, and consequently the Government positions which required training in this field remained vacant. My appointment to the staff of the Bureau of Fisheries as a naturalist of the Albatross was made on the basis of Section 10, Rule 2, of the Civil Service Commission which gives a Commissioner authority to fill existing vacancies without competitive examination. The position of naturalist of the Albatross remained vacant for nearly two years before my appointment on December 20, 1921.

Oyster research at this time centered in New Jersey where Dr. Thurlow C. Nelson continued the work started by his father, with special attention to behavior of oyster larvae, feeding of oysters, and shell movements. He made the first attempts to record behavior of the mollusk in its natural habitat; by using a kymograph he observed the peculiar contractions of the adductor muscle during spawning.

The importance of filtration of water by oysters and other pelecypods was already understood at that time, especially in its sanitary aspects. The question of obtaining pure oysters, devoid of contamination by pathogenic bacteria, became an acute and vital issue to the industry. The consuming public had no assurance that shellfish sold on the market came from unpolluted water and therefore was not dangerous to eat. A disastrous crisis in the oyster industry caused by the epidemic in Chicago in 1924-25 left the leaders of the industry disorganized and in great doubt concerning the future of their business. I clearly remember the great tension felt by everybody present at the meeting called in 1925 by the Commissioner of Fisheries to find a practical solution for a difficult situation. Sales dropped almost to zero; hundreds of letters were received every week by the Bureau asking if all oysters were contaminated, and several housewives had written us that they discontinued buying chicken because poultry was fed on oyster shells. The Government officials, members of the state and federal public health services, two or three biologists, and many oyster growers were present at the meeting. The main scientific questions under discussion were the rate of water filtration and the effect of temperature on feeding and so-called hibernation of oysters. I was asked how temperature affects the rate of feeding of the oyster--and was not able to give an answer because the problem had not been studied. From bacteriological data it became evident that the Bacterium coli (now Escherischia coli) score in oysters is lowest in winter and highest in summer. Bacteriologists (Gorham, Gage and others) concluded from these observations that the difference must be due to suppression of vital activities by low temperature and called it hibernation. As a consequence of the conference I started a study of the ciliary motion of the gills and found that this motion is suppressed at temperatures

below 48°F. In the course of this study two methods were developed for measuring the volume of water passed through the gills. In the first method rubber tubing was introduced into the cloaca and made fast by cotton paddings. The free end of the tubing was attached to a horizontal glass tube of known diameter and graduated in centimeters. The velocity of the current inside the tube was measured by adding, through an inverted T tube, small quantities of carmine suspension which formed a clearly visible cone moving along the entire length of the tube. The so-called "carmine cone" method proved to be useful for rapid bioassays in cases when it was necessary to demonstrate the effects of toxic substances on ciliary mechanisms.

The other method involved the use of one large and one small connecting vessel in which the level of running water was kept constant. An oyster with the rubber tubing inserted into the cloaca was placed into the large vessel; the free end of the tubing was connected to a glass tube inserted in the wall between the two vessels. Water pumped by the oyster into the small vessel was collected through an overflow, measured and analyzed. With modifications added by various investigators the method became generally used in studies of feeding and respiration of oysters.

Determination of the rate of water pumping was much improved by Thurlow C. Nelson's apron technique which consisted of wrapping the oyster in plastic in such a way as to intercept the excurrent water. At the same time Nelson called our attention to the existence of the promyal chamber in the species of oysters which are now grouped under the generic name Crassostrea. The promyal chamber was depicted in earlier work of J. L. Kellogg (1892) but the significance of this asymmetrical area on the right side of the body was overlooked. The importance of the promyal chamber fully justifies the splitting of the genus Ostrea into two genera, Crassostrea with the chamber and Ostrea without it.

Almost every oyster biologist of the last quarter of a century was more or less involved in a study of sex, spawning, and setting of oysters. In a series of carefully documented papers W. R. Coe (1936, 1938) showed that along the coast of the United States from New England to the Gulf of Mexico young oysters, less than one year old are predominantly males. The sex ratios are, however, highly variable. In northern localities there may be only 8 females to 100 males while in southern waters the ratio increases to an average of 40 females to 100 males. The reasons for the diverse sex ratios are unknown. The differences may be attributed according to Coe to local races with differing genetic factors and to environmental conditions. During the second year of their life some of the males change sex and become females. In this way a normal 1:1 sex ratio is restored.

A. B. Needler (1932) found that adult C. virginica also change their sex. Her observations were fully confirmed by my experiments

with about 200 five-year-old oysters which were kept in the bay near the laboratory for six years. Every summer each of these oysters was induced to spawn and its sex ascertained. About 10 percent of them changed sex annually either from male to female or vice versa. One oyster changed its sex five times. Sex changes in adult Japanese oysters, C. gigas, were described by I. Ameniya (1929). Rapid sex changes in the hermaphroditic O. edulis and O. lurida were reported in considerable detail by J. H. Orton (1927-33, 1936), R. Sparck (1925) and W. R. Coe (1932).

Hundreds of papers in oyster literature deal with the effect of temperature of water on spawning. From purely descriptive data it is difficult to determine the nature of this relationship. My experimental studies of the physiology of reproduction of C. virginica (Galtsoff, 1938) showed the fundamental differences between male and female spawning. The discharge of ripe eggs by the female is accomplished by a complex process in which eggs are first discharged into the suprabranchial chamber, then forced through the gills into the mantle cavity, and finally are thrown off by violent movements of the valves. Spawning of the male is much simpler; sperm is discharged into the cloaca and is dispersed in water by the outgoing current. No definite temperature of spawning can be established for a given population of oysters. In my experiments specimens at different degrees of ripeness spawned at any temperature between 21° and 32°C. Some of them were able to spawn only under the combined influence of temperature and chemical stimulation by sperm. I would prefer to think of a critical condition of a fully ripe organism ready to discharge its sexual products rather than the existence of critical temperatures. Experimental evidence is against the latter view. The trigger-like effect in releasing sex products from ripe gonads may be produced by slight changes in temperature at different levels, by chemical stimulation, and by a combined effect of both agents. An attempt to explain the differences in the temperatures of spawning of C. virginica living at different latitudes was made by L. A. Stauber (1947) by assuming the existence of "physiological races". This view is shared by some biologists (V. L. Loosanoff and C. A. Nomejko, 1951) but in my opinion the final test should come from study of the genetics of the oyster. The existence of a "physiological race" can be proved only by breeding experiments and by testing under controlled conditions the spawning reaction of specimens of known genetic origin.

Spawning of oysters has been associated frequently with lunar phases. The work of the Milford Laboratory under Loosanoff demonstrated that such relationship does not exist in C. virginica in Long Island Sound, although according to P. Korringa (1947) it is present in O. edulis.

Practical considerations demanded that oyster biologists predict time of spawning and setting. Based on many years of observations the laboratory at Milford arrived at a general empirical

formula which has proved to be useful. A slightly different but also empirical method is being used by the oyster biologists of the Pacific Coast in predicting spawning and setting of C. gigas. There are so many factors affecting the life and survival of oyster larvae that probably many years of intensive research will pass before the prediction of time and intensity of setting can be placed on a sound scientific basis.

The oyster larva still remains a very elusive little creature. Correct identification of larvae of oysters and other pelecypods presents great difficulty. Many so-called quantitative records of the abundance of larvae in various estuaries and sounds are unreliable because of probable errors of identification. One incident, which I remember very clearly, illustrates this point. An oyster culturist employed by the Conservation Commission of one of the coastal states reported faithfully every year the number of oyster larvae found in July and August in the waters under the jurisdiction of the state. One day he showed me his samples which supposedly contained many thousands of larvae in advanced stages of development. I saw under a microscope numerous round diatoms of the genus Coscinodiscus but no pelecypod larvae. The man was quite indignant when I tried to explain the difference between the two forms; he told me that what he was doing was the established practice of his office and, "anyway," he added, "we do not want to be troubled with scientific technicalities".

In the last ten years the problem of identification of larvae was greatly facilitated by the work of the Milford Laboratory which distributed microscopic preparations of larvae, the identity of which was beyond any doubt because they were all produced from eggs fertilized and developed in the laboratory.

A classification of lamellibranch larvae, based on the structure of hinge and detailed descriptions of larvae of several species of American and European oysters greatly facilitates identification (G. Ranson, 1948; C. B. Rees, 1950).

Although we have at present a fair idea of the time and place of setting of oysters in various localities, the questions how and why larvae select definite vertical levels for attachment, and what causes their aggregation in one place in preference to another, remain unanswered. Hydrographical studies conducted in Chesapeake Bay, jointly by D. W. Pritchard (1953) of the Chesapeake Institute, the Virginia Fisheries Laboratory, and the U. S. Fish and Wildlife Service, show that the pattern of circulation in a tidal estuary is a major factor in the transport and retention of oyster larvae. This factor is greatly influenced by prevailing winds. In this situation the density of water may play a predominant role in influencing vertical distribution of larvae, an idea developed long ago by New Jersey biologists who studied the setting of oysters in Barnegat Bay.

Correct interpretation of ecological factors which control setting is difficult because of the insufficiency of experimental data concerning the physiology and behavior of oyster larvae. So far, the experimental approach to the problem has been impossible because of the uncertainty in obtaining sufficient numbers of healthy larvae of known age for this type of study.

The need for raising oyster larvae in tanks was recognized long ago. In 1920, Dr. W. F. Wells developed a technique for growing larvae in large jars in which sea water was changed by centrifuging. For several years he conducted an oyster hatchery at Oyster Bay and later transferred his operation to the plant of the Blue Point Oyster Company at West Sayville. Although a fairly large number of young oysters was produced in this way, the method was too complex and uncertain to be of practical value.

Food and feeding is the main problem in raising oyster larvae. Great advances in this problem were made in 1940 by J. R. Bruce, M. Knight and M. W. Parker (1940) in England. They definitely established the feasibility of rearing larvae of O. edulis by feeding several species of flagellates. In 1949 and 1950 Imai and Hatanaka in Japan were successful in raising C. gigas and other species by feeding larvae with naked flagellates which they cultured in tanks. In this country V. L. Loosanoff (1954) and H. C. Davis (1953) at the Milford Laboratory developed an excellent technique of raising pelecypod larvae by feeding them several species of naked flagellates and by determining the nutritive value of these microorganisms. The results open up new and broad possibilities for scientific research on larval physiology and ecology.

Ecological studies conducted during the past 25-35 years failed to answer the most important question--why certain grounds produce an excellent set but are not suitable for rapid growth and fattening of marketable oysters, while other grounds, not far away from the first ones, are good for growing marketable stock but cannot be used to catch spat. Statistical study of associations or correlations between the setting and various factors of the environment so far have failed to produce tangible results. I am certain that the solution of this problem eventually will be found through a well planned study of the physiology of feeding and food requirements of larval and adult oysters.

The knowledge of feeding requirements is equally essential for understanding the reasons for differences in the productivity of oyster bottoms. There are many places along the coast where oyster beds located only a couple of miles apart are markedly different in their productive capacity and in the flavor of oyster meat. Routine biological and chemical analyses show no significant differences between the waters of the adjacent bottoms. Apparently other components of oyster environments which are not disclosed by present methods of study are responsible for differences.

It has been well established by numerous investigations conducted in this country and in Europe that chemical composition of oyster meat does not remain constant throughout the year. Particularly spectacular is the seasonal cycle of glycogen. The accumulation of this carbohydrate usually takes place in the autumn when oysters become fat. We still know very little about the carbohydrate metabolism of lamellibranchs. This consists of complex biochemical reactions in which several enzymes are involved. Likewise, the breaking down of carbohydrate in the oyster has not yet been studied. It is reasonable to assume that an insulin-like substance may be present in the oyster but so far attempts to extract insulin from oysters have given negative results. Work along these lines appears to offer interesting possibilities for further research.

Digestion in the oyster and various enzymes involved in this process were studied by C. M. Yonge (1926) in England. The continuation of these investigations using modern techniques appears to be very promising, since the question of the ability of oysters to digest certain types of food has not yet been settled.

Pathology of the oyster is a relatively new science. Most parasites and commensals found in the oyster, such as protozoa, sponges, crustacea and worms, are not pathogens in a true sense of the word although they may inflict damage to the tissues of the host. The discovery of the fungus-like microorganism Dermocystidium marinum a few years ago by J. G. Mackin, H. M. Owen and A. Collier (1950), and the studies by S. M. Ray (1954), focused the attention of oyster biologists on this dangerous pathogen as a probable cause of extensive mortalities among southern oysters. It is reasonable to expect that further pathological studies may disclose other types of infection including disease-producing viruses.

Many research studies conducted in the United States were concerned with the problem of the decline in oyster production. The question is of great complexity because the productivity of shellfish grounds depends on interaction of many physical and biological factors. The annual production of oysters in the United Stated has declined from an average level of 165 million pounds of meat during the decade 1893-1902 to 77 million pounds per annum in 1943-1952 (P. S. Galtsoff, 1956). Several factors may be responsible for the decrease, but the primary cause is the destruction of public grounds especially in the Middle Atlantic and South Atlantic States. The acreage of productive oyster bottoms in these states has been steadily decreasing through overfishing, dredging of coastal waters for navigation, sedimentation, and pollution. Lack of management or ineffective management of public grounds has also contributed to the general trend and may be considered as a major factor in the depletion of oyster resources. Numerous studies conducted by various states and federal organizations demonstrated that the production of oyster bottoms cannot be maintained on a sustained basis without applying

oyster-farming methods. Several years ago the problem of state management was investigated in Maryland by J. B. Engle of the U. S. Fish and Wildlife Service, and by our present director of the Oyster Institute. The cost of rehabilitation of the depleted oyster grounds was determined and several possibilities were found for developing seed-producing areas of the state. Because of high initial cost of this type of work, state governments are not in a position to undertake large scale projects of rehabilitation. This could be accomplished by private oyster farmers, but strong opposition against private leasing prevails in many southern states and usually succeeds in preventing passage of necessary legislation.

About 25-30 years ago the feeling against private oyster farming in some communities along the Atlantic seaboard was so strong that anybody who publicly advocated this course could have met with physical violence. On one occasion I was threatened with this possibility after a discussion of local oyster problems at a public meeting in a small town.

At present the low level of productivity of public grounds is maintained by administrative measures designed to restrict the efficiency of harvesting. The use of inefficient and therefore expensive methods of fishing is, however, against the general trend in other industries which try to attain the highest efficiency through mechanization and automation.

No oyster biologist in the employ of a state or federal agency can escape being involved in the problem of pollution. Increased discharges of domestic sewage from municipalities and of trade wastes from industrial centers greatly damage shellfish bottoms. According to the Public Health Service statement in a publication entitled, "Environment and Health" (1951), there were in 1950-51 over 22,000 sources of pollution in the United States, 11,800 municipal sewer systems and 10,400 factory waste outlets. Only 9,300 treatment plants were in operation; the remaining sources discharged their wastes without even a partial treatment. Pollution of inshore waters became so great that at least 400 shellfish growing areas were condemned by state authorities. Damages caused by pollution are extensive. For instance, in New York-New Jersey harbor, water pollution has caused an estimated 100 million dollars of damage in 20 years to fisheries, recreation, and property values.

Biological aspects of water pollution are well understood. But pollution is primarily a social problem, the solution of which can be attained through awareness of its great dangers and education of the general public. As Representative Karl E. Mundt stated in his defense of the Anti-Pollution Bill in 1945, "Of all the natural resources, water today suffers from the greatest amount of public neglect."

Numerous investigations conducted in Europe and in this country have demonstrated the toxicity of various chemical compounds that are discharged with industrial wastes. The deleterious effect of pollution is frequently difficult to prove because in a complex ecological environment the injury caused by poison may be masked. Pollution frequently weakens organisms, makes them more susceptible to changes in the environment, and interferes with reproduction and feeding. Mortality may be due to combined effect of these conditions.

Virtually every state and federal laboratory of this country has been engaged in the problem of control of predators. Gastropod snails are undoubtedly the most destructive enemies of the oyster. Partial success in controlling predators has been achieved by trapping, dredging, barrier construction, and other physical means. In the past, careless bedding of native oysters or introduction of foreign species were the main causes of the wide distribution of carnivorous drills. These snails have only limited powers of locomotion but are brought to new territories with shipments of infested oysters. Their inroads are especially destructive in a new environment in which natural enemies are absent. Suffice to mention the introduction of Urosalpinx into European waters and the spread of Tritonalia japonica in Puget Sound.

The future welfare of the oyster industry calls for the solution of the following problems: reliable production of seed oysters; production of rapidly growing oysters with high-glycogen and high-solid contents; selection of disease-resistant races; improvement of methods of self-purification of oysters; scientific evaluation or appraisal of oyster bottoms based on their productive capacity; and development of oyster pond culture in tidal marshes and other areas not used at present for oyster farming.

Solution of these problems presents a challenge to young oyster biologists who are just entering this field of research. From the background of heretofore accumulated studies they may proceed with critical and basic research intended to answer the following questions. How oyster larvae feed and grow, how they react to physical and chemical changes of the environment and why they set in certain places and levels and not in others. To answer these questions elaborate physiological studies should be conducted simultaneously with ecological observations.

Production of oysters of highest quality, judged not by their size alone, but by flavor and high content of solids and glycogen is essential for the future of the industry. The problems of carbohydrate metabolism, feeding, and digestion should be studied and understood in order to attain this goal. It is futile to enumerate the various organisms that may be found in the stomachs of the oyster without knowing their nutritive value. Advance in physiology of nutrition in shellfish will lead to establishment of feeding or fattening basins or ponds in which shellfish may be rapidly conditioned for market.

The progress in methods of raising oyster larvae gives us assurance that the study of oyster genetics may be undertaken with reasonable expectation of success. Modern genetics tells us that variability and adaptability of a species depend on gene combinations and chromosome changes. The oyster is an extraordinarily adaptable and plastic organism. It can be assumed on theoretical grounds that wild populations contain many mutants which can be selected by proper breeding techniques. Races having desirable characteristics can be bred and used for establishing breeding stocks of particular qualifications needed for local conditions. The work along these lines requires the establishment of oyster breeding centers with adequate numbers of tanks or ponds, adequate water supply and culture houses for mass production of microorganisms needed as food for larval and young oysters. Experiments on hybridization can be conducted in these places in order to obtain the most desirable hybrids.

Ecological studies in the future should consider the oyster in relation to its physical and biological environment. Emphasis should be placed therefore on the factors which control the entire community of an oyster bottom. It seems erroneous to concentrate on a study of the biology of a single species without paying attention to other organisms which form an integral part of an ecological system.

The struggle for protection of our inshore waters and oyster grounds from pollution is one of the major tasks of the conscientious biologist who feels moral responsibility towards his country. Ample scientific evidence permits us to state that any pollution of water is bad and that no harmless pollution ever existed in spite of the claims made to the contrary by some industrialists. All types of pollutants which existed in the pre-atomic age have one common characteristic; after being discharged into natural waters they are oxidized and undergo other chemical changes which eventually render them harmless.

At present we are facing a more serious problem of safe storage and elimination of radioactive wastes which cannot be destroyed by ordinary methods known to us. These wastes can be only isolated in special containers or dispersed in water or air in order to reduce the level of their radioactivity. There are at present more than 4,000 establishments in our country using radioactive isotopes which have to be disposed of without endangering life. With rapid industrial development of nuclear energy the problem will soon reach a critical stage. The ability of shellfish to accumulate metals in their bodies and shells makes them particularly susceptible to certain radioactive elements. This new situation confronting the oyster industry should be given serious consideration. I trust that the realization of dangers involved in the radioactive pollution of sea water will stimulate intensive research and that a satisfactory solution of the problem will be found in the nearest future.

It is clear from my presentation that considerable investment of public and private funds is necessary to implement the outlined program. No doubt the oyster industry will bear a fair share of this burden. I believe the industry should do it if it wants to survive.

Centuries ago oysters constituted a cheap food, both in Europe and in this country. The following quotation from Dickens' "Papers of the Pickwick Club" expresses this idea. "It is a very remarkable circumstance, sir," said Sam, "that poverty and oysters always seem to go together--the poorer a place is, the greater the call there seems to be for oysters."

Very rapidly the oyster became a luxury in England while in this country it continued to be inexpensive and available to persons of low income groups. The situation changed during the last decade and the American oyster moved into a class of luxury food which poor people can no longer afford. Being a low energy food, valuable for its nutrient quality, but providing much less calories than other types of food, they oyster probably will remain in this category. It is imperative, therefore, that greater consideration be given by oyster producers to the attractiveness, the flavor, the content of solids and the purity of their product. To solve these problems they have to rely on the scientific resources of modern science and the skill and imagination of young biologists.

References

Ameniya, I. 1929. On the sex-change of the Japanese common oyster, Ostrea gigas. Proc. Imp. Acad. Japan (Tokyo) 5(7): 284-286.

Bruce, J. R., M. Knight and M. W. Parke. 1940. The rearing of oyster larvae on an algal diet. Jour. Mar. Biol. Assoc. 24: 337-374.

Coe, W. R. 1932. Development of the gonad and the sequence of the sexual phases in the California oyster (Ostrea lurida). Bull. Scripps Inst. Oceanog. Univ. Calif. Tech. Ser. 3(6): 119-144.

1936. Environment and sex in the oviparous oyster Ostrea virginica. Biol. Bull. 71: 353-359.

1936. Protandry in the Virginian oyster. Anat. Rec. 67 (Suppl. 1): 89.

1938. Primary sexual phases in the oviparous oyster. Biol. Bull. 74: 64-75.

Coupin, H. 1900. Sur les fonctions de la tige cristalline des acephales. Compt. Rend. Acad. Sc., Paris, 130: 1214-1216.

Davis, H. C. 1953. On food and feeding of larvae of the American oyster, C. virginica. Biol. Bull. 104: 334-350.

Gage, S. DeM., and F. P. Gorham. 1925. Self-purification of oysters during hibernation. Amer. Jour. Pub. Health 15: 1057-1061.

Galtsoff, P. S. 1926. New methods to measure the rate of flow produced by the gills of oyster and other molluscs. Science 63: 233-234.

1928. The effect of temperature on the mechanical activity of the gills of the oyster (Ostrea virginica Gm). Jour. Gen. Physiol. 11: 415-431.

1935. The biology of the oyster in relation to sanitation. Amer. Jour. Pub. Health 26(2): 245-247.

1937. Observations and experiments on sex-change in adult American oysters, Ostrea virginica. Biol. Bull. 78: 356.

1938. Physiology of reproduction of Ostrea virginica Part I, II. Biol. Bull. 74: 461-486; 75: 286-307.

1940. Physiology of reproduction of Ostrea virginica, Part III. Biol. Bull. 78: 117-135.

1956. Ecological changes affecting the productivity of oyster grounds. Trans. 24th North Amer. Wildlife Conference, March 5-7, 1956: 408-419.

Gorham, E. P. 1912. Seasonal variations in the bacterial contents of oysters. Amer. Jour. Pub. Health 2: 23-27.

Heide, A. de. 1686. Experimenta circa sanguinis missionem, fibras motrices, utricam marinam, etc. - accedunt auctoris observationes medicoe nec non anatome Mytuli: 35-36. Editio Nova. Amsterdami.

Imai, T. and M. Hatanaka. 1950. Studies on marine non-colored flagellates, Monas sp., favorite food of larvae of various animals. Sci. Rep. Tohoku Univ. 4th Ser. 18(3): 304-315.

Kellogg, J. L. 1892. A contribution to our knowledge of the morphology of lamellibranchiate molluscs. Bull. U. S. Fish Comm. 10: 389-436.

Korringa, P. 1947. Relations between the moon and periodicity in the breeding of marine animals. Ecol. Monogr. 17: 347-381.

Loosanoff, V. L. 1954. New advances in the study of bivalve larvae. Amer. Scientist 42: 607-624.

------ and C. A. Nomejko. 1946. Spawning and setting of the American oyster, O. virginica, in relation to lunar phases. Ecology 32: 113-134.

1951. Existence of physiologically-different races of oysters, Crassostrea virginica. Biol. Bull. 101: 151-156.

Mackin, J. G., H. M. Owen, and A. Collier. 1950. Preliminary note on the occurrence of a new protistan parasite, Dermocystidium marinum n. sp., in Crassostrea virginica (Gmelin). Science 111: 328-329.

Needler, A. B. 1932. Sex reversal in Ostrea virginica. Contr. Can. Biol. and Fish. 7(22): 285-294.

Nelson, T. C. 1918. On the origin, nature, and function of the crystalline style of lamellibranchs. Jour. Morph. 31: 53-111.

1924. The attachment of oyster larvae. Biol. Bull. 66: 143-151.

1925. Recent contribtuions to the knowledge of the crystalline style of lamellibranchs. Biol. Bull. 49: 86-99.

1928. Investigations of spawning and setting of oysters in Barnegat Bay, New Jersey. Rept. Dept. Biol. N. J. Agric. Exp. St. 1927: 77-83.

1928. On the formation of saliniclines in Barnegat Bay, New Jersey, with observations of the reactions of oyster larvae to salinity gradients. Anat. Rec. 41: 84-85.

1936. Water filtration by the oyster and a new hormone effect upon the rate of flow. Proc. Soc. Exp. Biol. and Med. 34: 189-190.

1938. The feeding mechanism of the oyster. I. On the pallium and the branchial chambers of Ostrea virginica, O. edulis and O. angulata, with comparisons with other species of the genus. Jour. Morph. 63: 1-61.

Orton, J. H. 1927-1933. Observations and experiments on sex-change in the European oyster, Parts I, III, IV. Jour. Mar. Biol. Assoc. 14: 967-1045; 19: 1-53.

1936. Observations and experiments on sex-change in the European oyster, Ostrea edulis L. Mem. Mus. Roy. Hist. Nat. 2nd Ser., Fasc. 3: 997-1055.

------ and C. Amirthalingam. 1930. Observations and experiments on sex-change in the European oyster (O. edulis) Part II. On the gonad of egg-spawning individuals. Jour. Mar. Biol. Assoc. 17: 315-324.

Pritchard, D. W. 1953. Distribution of oyster larvae in relation to hydrographic condition. Proc. Gulf and Carribbean Fish. Inst. 5th Ann. Sess., 1952: 123-132.

Public Health Service. Federal Security Agency. 1951. Environment and Health. 152 pp. Washington, D. C.

Ranson, G. 1948. Prodissoconches et classification des ostreides vivants. Bull. Mus. Nat. Belg. 24(42): 1-12.

Ray, S. M. 1954. Biological studies of Dermocystidium marinum a fungus parasite of oysters. Rice Inst. Pamphlet, Special Issue, Nov. 1954. 114 pp.

Rees, C. B. 1950. The identification and classification of lamellibranch larvae. Hull Bull. of Mar. Ecol. 3(19): 73-104.

Sparck, R. 1925. Studies on the biology of the oyster (Ostrea edulis) in the Limfjord, with special reference to the influence of temperature on sex-change. Rept. Dan. Biol. Sta. 30: 1-84.

Stauber, L. A. 1950. The problem of physiological species with several references to oysters and oyster drills. Ecology 31: 109-118.

Yonge, C. M. 1926. Structure and physiology of the organs of feeding and digestion in Ostrea edulis. Jour. Mar. Biol. Assoc. 14: 295-386.

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156 Paul S. Galtsoff, Shellfish Laboratory, Woods Hole, Massachusetts. Ultrastructure of the ciliated epithelium and the correlation between the ciliary motion and muscular contractions in the gills of *Crassostrea virginica*. (15 min.)

Electron microscopy reveals the following structural elements of ciliated cells of oyster gills: the cuticle, consisting of tightly packed microvilli; the transverse plates at the proximal ends of cilia; the cylindrical and slightly assymmetrical basal corpuscles with a knob on one side; and a pair of rootlets emerging from the proximal end of each corpuscle. Every rootlet crosses over the rootlet of the nearest corpuscle and appears to fuse or at least to make a close contact with its opposing number. There is no direct connection between the basal corpuscles. Structure of ciliary apparatus suggests that the rootlets play a role in the coordination of ciliary motion.

Rate of ciliary currents over the exposed, but intact, surface of the gill was measured by recording the time of passage of small particles of ground shell material along the filaments and the terminal groove. Sudden slowing down and complete cessation of currents was observed to coincide with spontaneous contractions of the muscles of the gills and of the adductor. Cessation lasted from a fraction of a minute to several hours, then was resumed at the former rate. The renewal of ciliary motion coincided with the relaxation of the adductor. Observations suggest a neuroid transmission of inhibition which coincides, and possibly originates, with the spontaneous muscular contractions.

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ON DEVELOPMENT OF EARLY STAGES OF UROSALPINX CINEREA (SAY) AT CONSTANT TEMPERATURES AND THEIR TOLERANCE TO LOW TEMPERATURES

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ON DEVELOPMENT OF EARLY STAGES OF UROSALPINX CINEREA (SAY) AT CONSTANT TEMPERATURES AND THEIR TOLERANCE TO LOW TEMPERATURES

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One of the most destructive predators of young oysters in Long Island Sound is the oyster drill, *Urosalpinx cinerea* (Say). However, our knowledge of its early development and the tolerance of its egg cases to winter temperatures, when deposited late in the season, remains incomplete. Carriker's (1955) comprehensive review of the literature on oyster drills clearly shows that most workers, while mentioning the time needed for ova to develop into young conchs, neglect to give the temperature ranges at which development occurs. Among the few who offer information on this subject, Haskin (1935) states that within the temperature range of 23.3° to 29.1° C., 18 to 25 days are needed for the first protoconch to hatch. Federighi (1931) reports that within a range of 18.0° to 32.0° C., it takes approximately 40 days to complete the development. Stauber's field data (Carriker, 1955) indicate that within the temperature range of 15.0° to 25.0° C., from 45 to 78 days are required for drill eggs to develop. Cole (1942) reports 27 to 32 days at 22.6° C., and 44 to 55 days at 18.3° C.

As can be seen from the above references, the information is insufficient to form precise conclusions. We, therefore, devised experiments to determine more accurately the rate of early development of drills at several constant temperatures, which may be encountered within the temperature range of Long Island Sound or adjacent waters.

It was also considered of theoretical interest and practical importance to learn the fate of the eggs deposited so late in the fall that they cannot complete development. Such egg cases, collected during the winter from subtidal and intertidal zones, frequently contain live ova and veligers. Yet, no systematic observations on whether these eggs and embryos can survive the winter and be released in the spring have ever been made. If these embryos could develop, they would have an early start, thus adding to the destructive potential of the next year-class of drills.

Methods

Egg cases were obtained from drills maintained in the laboratory at 20.0° C. Preliminary experiments were made with egg cases scraped from the shells of the oysters used to feed the drills and from the glass sides of the aquarium. They were examined under a dissecting microscope and only those that had non-segmented ova, a soft pliable outer membrane, and a translucent bluish-white appearance were selected. It was estimated that such egg cases had been deposited within three days. Later, clusters of young oysters were placed in the aquarium overnight, and the egg cases deposited on them were used in the experiments. Thus, the age of these egg cases was known to be not more than 16 hours.

To determine the rate of development of ova at different constant temperatures, 20 egg cases were placed in perforated, transparent, plastic containers weighted with lead, which were then put in trays. Each tray was supplied with a constant flow of sea water at a salinity of about 25‰, and the temperature of the water was maintained at 7.5°, 10.0°, 15.0°, 20.0°, 25.0° and 30.0° C., controlled to within ± 1.0° C. (Loosanoff, 1949).

In addition to conducting experiments at the above constant temperatures, egg cases were also kept at chilling winter temperatures just above freezing, and others were exposed to sub-freezing temperatures in and out of sea water. For observations on the effects of the chilling temperature, 26 egg cases, dredged from New Haven Harbor on December 5, 1955, were suspended in outdoor tidal tanks and systematically examined until March 22, 1956. Egg cases were also taken in winter from an aquarium kept at 20.0° C. and gradually conditioned to the Harbor water temperature which, at that time, was approximately 1.3° C. On January 7, 1956, they were placed in the Harbor and kept there until July 20, 1956.

To expose the egg cases to sub-freezing temperatures, they were placed in the freezing compartment of a refrigerator. In the first experiment the temperature of the compartment was − 12.0° C. (± 1.0° C.), and in the second, − 16.0° C. (± 1.0° C.). In each experiment the egg cases, with ova and veligers, were preconditioned in sea water to 3.0° C. Altogether nine plastic boxes, each containing 20 egg cases, were used. Six containers were without water and three contained 100 ml. of sea water each. One container without water was removed at the end of the first half hour and the others at half-hour intervals thereafter, up to three hours. The first group of egg cases kept in sea water was removed after one hour of exposure and the others at hourly intervals. In later, similar experiments, the egg cases were left at both temperatures for two, four and six hours.

Development at Six Constant Temperatures

We determined the number of days required at different temperatures for development of ova (Fig. 1) to the following embryological stages: early larvae (Fig. 2), shelled veliger (Fig. 3), and protoconchs (Fig. 4). The time needed to reach the early veliger stage decreased with increases in temperature from 10.0° to 30.0° C. (Table I). The groups kept at 30.0° and 25.0° C. attained the shelled veliger stage between the fourth and seventh days. However, it required eight additional days for those kept at 20.0° C. to reach the same stage, and even longer for those at 15.0° and 10.0° C.

In spite of the longer time required for ova at 20.0° C. to develop to the shelled veliger stage, they had reached the protoconch stage by the 22nd day, the same as the groups kept at 25.0° and 30.0° C. Nevertheless, the egg cases kept at 30.0° and 25.0° C. started releasing young conchs on the 22nd day, and continued for 16 days for both temperature groups. None of those kept at 20.0° C. were released until the 30th day, and those kept at 15.0° C. were not released until the 56th day. Thus, while there was only eight days' difference in the time required to reach the protoconch stage between the egg cases kept at 20.0° C. and those at 15.0° C., there was 26 days' difference in the time of release of the first young conchs. Moreover, at 20.0° C. the period between the first conch released and the last was only 13 days, while for the 15.0° C. group 22 days were needed.

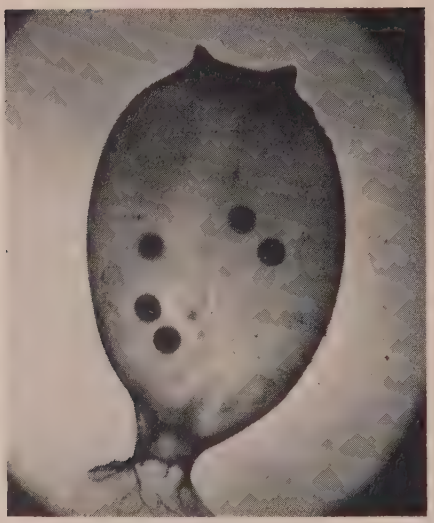

FIGURE 1. Egg case of *U. cinerea* with five ova. ×10.

At 10.0° C. the ova required 66 days to reach the early veliger stage, and 84 days before the shelled veligers appeared. At 7.5° C. no development occurred during the 54 days. At the end of those periods both the 10.0° C. and 7.5° C. groups were placed in water of 20.0° C. to determine whether they would develop under the new temperature condition, regardless of their previous treatment. Only 65 per cent of the egg cases kept originally at 10.0° C. produced conchs, while no development occurred in the former group at 7.5° C. Since the egg cases at 7.5° C. were apparently adversely affected before being placed at 20.0° C., it may be inferred that temperatures at 7.5° C. and lower not only arrested development, but killed the eggs after a prolonged period of exposure.

Our results indicated that the optimum temperature for drill development was

TABLE I

Number of days for ova to develop to various stages at constant temperatures and the percentage of egg cases producing young conchs

Stage of development	Temperatures					
	7.5° C.	10.0° C.	15.0° C.	20.0° C.	25.0° C.	30.0° C.
Early veliger	54*	66	10	7	4	2
Shelled veliger	—	84**	25	15	7	7
Protoconch	—	—	30	22	22	22
Release of young conchs	—	—	56–78	30–43	22–38	22–38
Percentage of egg cases producing young conchs	0%	65%	90%	100%	95%	90%

* No development.

** Placed in water of 20.0° C.

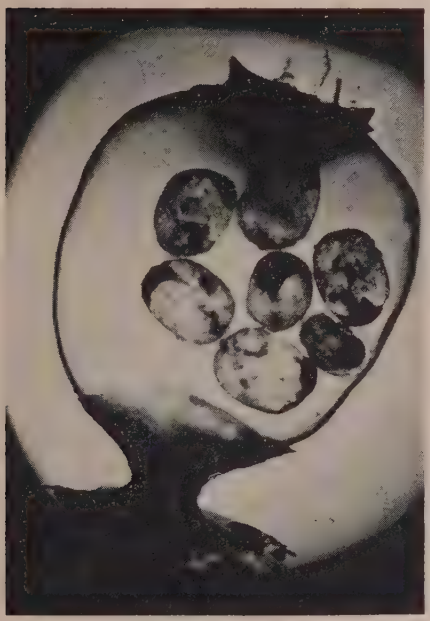

FIGURE 2. Egg case, with outer membrane removed, containing early motile larvae just before a true velum is developed. Larvae at this stage have a gut and can feed on particulate matter by means of currents created by the cilia. × 10.

FIGURE 3. Egg case, with outer membrane removed, containing veliger larvae, with foot and velum present, after torsion has occurred. The shell has begun to form along the outer edge of the mantle. × 10.

about 20.0° C. (Table I). However, since the rate of development was faster at 25.0° C. and the difference in the percentage survival of egg cases producing young conchs between 20.0° C. and 25.0° C. was small, it was considered possible that the optimum was above 20.0° C. Therefore, a second experiment was conducted at 20.0° C. and 25.0° C., using 20 egg cases in each temperature group, and the percentage survival of ova determined. At 20.0° C., 139 out of 176 ova, or 78.9 per cent, developed to the protoconch stage, as compared to 96 out of 168 ova, or 56.8 per cent development, at 25.0° C. Thus, although the rate of development was faster at 25.0° C., the optimum temperature, from the standpoint of successful development to the young conch stage, appeared to be about 20.0° C. Moreover, at 20.0° C. the period for protoconch release was shorter than at any other temperature.

FIGURE 4. Egg case, with outer membrane removed, containing three early protoconch larvae which show partial spiral development and pigmentation. Note also the two undeveloped ova in the same egg case. × 10.

Since the egg cases in the first experiment were deposited within a period of three days, their age alone could not account for the difference of 13 to 22 days between the release of the first and last young conch. The conclusion that slight differences in the age of the cases are not responsible for pronounced differences in the time needed for release of young conchs of the same groups is further substantiated by our second experiment at 15.0° C. in which egg cases collected within a 16-hour period started releasing young conchs at 62 days and continued to do so for 19 days.

TOLERANCE TO LOW TEMPERATURES

To study the tolerance of egg cases to winter temperatures when exposed at low tide and to simulate tide pool conditions, cases containing ova and veligers were placed in water and exposed to air at the same sub-freezing air temperatures.

Because oyster drills in the intertidal zone stay close to the low water level and deposit their egg cases there, the latter are seldom exposed to air for more than an hour or two. Nevertheless, even under these conditions all the eggs would die if exposed to air temperatures around — 15.0° C. However, if the time of exposure at this temperature is reduced to a half hour, approximately 40 per cent may survive. At temperatures around — 12.0° C., five per cent could survive after two hours of exposure.

The survival was greater when the egg cases were protected by water (Table II). At exposure periods of two hours at air temperatures around — 12.0° and — 15.0° C., about 95 per cent of the eggs survived. The chance of survival of eggs in frozen tide pools would be much greater than in air, not only because of the

TABLE II

Survival of ova and veligers in egg cases of U. cinerea (a) submerged in sea water, and (b) when exposed in air, subjected to two sub-freezing temperatures. Survival is expressed in percentage of egg cases in which shelled veligers developed after returned to 20.0° C. sea water

Air temperature −12.0° C. (±1.0° C.)			Air temperature −16.0° C. (±1.0° C.)		
Length of exposure	Temperature at end of exposure (°C.)	Survival (%)	Length of exposure	Temperature at end of exposure (°C.)	Survival (%)
(a) submerged in sea water					
1 Hr.	— 1.8	100	1 Hr.	— 5.0	90
2 Hrs.	— 2.8	95	2 Hrs.	— 5.0	95
3 Hrs.	— 3.0	95	3 Hrs.	— 8.1	25
4 Hrs.	— 3.5	95	4 Hrs.	−12.0	25
6 Hrs.	— 7.5	85	6 Hrs.	−16.0	0
(b) exposed in air					
½ Hr.	−11.0	75	½ Hr.	−15.0	40
1 Hr.	−11.0	20	1 Hr.	−15.0	0
1½ Hrs.	−11.2	5	1½ Hrs.	−15.0	0
2 Hrs.	−11.5	5	2 Hrs.	−15.3	0
2½ Hrs.	−11.8	0	2½ Hrs.	−16.2	0
3 Hrs.	−12.4	0	3 Hrs.	−16.0	0

warmer temperatures of the water, but also because desiccation of the egg cases is inhibited. Usually when drill cases were exposed to the sub-freezing air temperatures they were desiccated to such an extent that their walls collapsed. In general, experiments showed that the percentage survival in both air and water decreased with increases in time of exposure and with decreases in temperature (Table II).

The resistance of eggs and embryos to low temperature was tested under more natural conditions when, on December 5, 1955, 26 egg cases, 11 of which contained ova to segmented stages and 15 contained veligers and shelled veligers, were dredged from New Haven Harbor. The bottom temperature was 7.1° C. and the veligers were observed revolving within their capsule. These cases were placed

in tidal tanks in water of 7.5° C. on December 6, 1955, and the veligers were still motile on February 16, 1956, 63 days later. The average water temperature during this period was 2.3° C. with a range from − 0.1° to 7.5° C. By March 22, however, the ova and segmented stages within the cases were disintegrated and the veligers were dead.

To supplement these observations 120 egg cases collected from the laboratory aquaria were conditioned gradually to the outdoor water temperature of 1.3° C. and placed in the Harbor on January 7, 1956. These egg cases were kept until July 20, 1956, but showed no evidence of development.

Discussion

The incubation times found in our experiments are in general agreement with the data of other authors. Thus, Haskin's (1935) report of 18 to 25 days as the time for the first young conchs to hatch at 23.3° to 29.1° C. agrees with our 22-day period at 25.0° C. Cole's (1942) findings of 27 to 32 days at 22.6° C. and 44 to 50 days at 18.3° C. for drills are again in agreement with our observations. If we interpolate our data, we obtain 30 to 38 days at 22.5° C. and 43 to 56 days at 17.5° C.

Compared to our results, Cole (1942) found that the surprisingly short period of only five days was required for all the young conchs to be released at 22.6° C. and only six days at 18.3° C. Cole does not give the number of egg cases used in this experiment and the short period he records may be the result of having very few egg cases, since we found considerable variation between egg cases at any one temperature.

Pope (Carriker, 1955) found that the period for protoconch release from an egg case or group of egg cases, which we assume were deposited at the same time and kept under identical conditions, extended from four to 38 days. He attributes this to an uneven development of the embryos, but we found the embryonic development within a single egg case to be generally uniform, except for malformed embryos and undeveloped ova. By the time of release, some of these are partly eaten by the normally developing drills or remain undeveloped to such an extent that they never emerge (Fig. 4). Considerable variation in the period of incubation, however, does occur between the egg cases deposited within a 16-hour period.

We observed that the greatest variation in hatching time between egg cases occurs after the protoconch stage, which may not be caused entirely by an uneven development of the embryos. Some protoconchs remain in their cases longer than others, which may be due to a variation in some mechanism releasing the egg case operculum. Variations in hatching may also be caused by the physical obstruction of the operculum opening which a protoconch may find too small. On one occasion we saw a young drill, emerging from a case, become entrapped in the operculum opening and block the passage for the remaining protoconchs for eight days.

Our experiments showed that although egg cases can withstand sub-freezing water temperatures for short periods, they cannot survive prolonged periods of chilling. At first it appears to be more drastic to subject the egg cases to sub-freezing temperatures rather than to temperatures above freezing but if, for ex-

ample, the permeability of the egg cases is affected, the osmotic malfunction progresses at a faster rate at chilling temperatures than at sub-freezing temperatures (Luyet and Gehenio, 1940). Chilling temperatures, as these authors point out, become lethal to protoplasm only after long periods. This may explain the survival of the egg cases which we kept in the tidal tanks for a period of 63 days and also the presence of egg cases observed by other workers during the winter months (Carriker, 1955).

The author wishes to thank Dr. V. L. Loosanoff for his suggestions and constructive criticism throughout the experimental work and both Dr. V. L. Loosanoff and Mr. H. C. Davis for the critical reading of this paper. I also wish to thank Mr. C. A. Nomejko for preparing the photomicrographs and tables.

Summary

1. The rate of ova development increases directly with the increase in temperature from 15.0° to 25.0° C. No increase in the rate of ova development was observed above 25.0° C.

2. Optimum temperature for ova development of *U. cinerea* of Long Island Sound appears to be 20.0° C., or between 20.0° and 25.0° C.

3. Egg cases of *U. cinerea* kept in sea water can withstand sub-freezing temperatures for longer periods than egg cases exposed to sub-freezing air temperatures.

4. In sub-freezing temperatures, the percentage mortality increases with the period of exposure and with a decrease in temperature.

5. Egg cases kept at 10.0° C. for as long as 84 days showed partial development and were capable of producing normal protoconchs when returned to 20.0° C.; whereas, egg cases kept at 7.5° C. for 54 days were not viable.

6. Our experiments and observations suggest that egg cases remaining through the winter in Long Island Sound will not contain viable ova in the spring.

LITERATURE CITED

Carriker, M. R., 1955. Critical review of biology and control of oyster drills, *Urosalpinx* and *Eupleura*. *Sp. Sci. Rept., Fish.* 148.

Cole, H. A., 1942. The American whelk tingle, *Urosalpinx cinerea* (Say), on British oyster beds. *J. Mar. Biol. Assoc.*, **25**: 477–508.

Federighi, H., 1931. Studies on the oyster drill (*Urosalpinx cinerea*, Say). *Bull. U. S. Bur. Fish.*, **47**: 85–115.

Haskin, H. H., 1935. Investigations on the boring and reproduction activities of oyster drills, *Urosalpinx cinerea* (Say) and *Eupleura* sp. *Unpub. Rept. U. S. Bur. Fish.*

Loosanoff, V. L., 1949. Method for supplying a laboratory with warm sea water in winter. *Science*, **110**: 192–193.

Luyet, B. J., and P. H. Gehenio, 1940. Life and death at low temperatures. Biodynamica, Normandy, Missouri.

A SUMMARY OF THE ACCOMPLISHMENTS OF THE FISH AND WILDLIFE SERVICE CLAM INVESTIGATIONS — 1948-1957

By John B. Glude, Chief, Clam and Chesapeake Oyster Investigations

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Research by the Clam Investigations which was sponsored by the Atlantic States Marine Fisheries Commission has been conducted in the following locations:

1. Cape May, New Jersey — summers of 1949-1951 in cooperation with Rutgers University.
2. Milford, Connecticut Shellfish Laboratory — 1949-1951 Culture of hard clam larvae.
3. Milford Shellfish Laboratory — 1950-1955 — Parasitology
4. Newburyport, Massachusetts — 1949-1955
5. Boothbay Harbor, Maine — 1949 to present
6. Kingston, Rhode Island — 1949 to present
7. Annapolis, Maryland — 1956 to present

Studies in New Jersey

Biologists employed by the Clam Investigations and working in cooperation with Rutgers University added to the knowledge of spawning and setting of hard shell clams, growth, mortality rates and formation of check marks on the shells of the soft shell clam.

Milford, Conn. Studies

Funds from the Clam Investigations were transferred to Dr. Loosanoff in 1950 and 1951 to initiate studies on the artificial propagation of hard shell clams. This project was expanded to include culture of the larvae of various species of mollusks and provided valuable information for identification of these larvae in plankton samples. Methods for artificial propagation have now been developed to the extent that commercial application in the production of hard clam seed seems practical. Scientists from other laboratories and interested members of the industry are now being trained in these techniques at the Milford laboratory.

Parasites of the soft shell clam were investigated at Milford, Connecticut to determine if parasites were the cause of mass mortalities

of soft shell clams which had been observed in Plum Island Sound, Massachusetts. These studies resulted in the discovery and identification of everal new species but none was believed to have been the cause of mass mortalities of clams.

Newburyport, Mass. Studies

The team of biologists stationed at this laboratory demonstrated the extent of predation by horseshoe crabs and green crabs on soft shell clams. Their experiments showed that planted clams survived if protected from predators by fences which they designed.

A mass mortality of soft shell clams in Plum Island Sound was discovered during the summer of 1949 and was reported. Bacteriological studies were conducted from 1949 to 1951 but disclosed no pathogenic bacteria which could be blamed for this mass mortality. No further extensive mortalities were observed after 1951 so there was no opportunity for further investigation of causative agents.

Clam farming experiments demonstrated that private farming of soft shell clams is promising if small seed is planted and is protected from predators.

Soft Shell Clam Studies — Boothbay Harbor, Maine

Investigations at this station along with those at Newburyport, Massachusetts accomplished the first objective of this investigation "To find the cause of depletion of soft shell clams in New England" by identifying the green crab as the principal cause. The increase in abundance of this crab during a cycle of warm winters are observed and recorded as well as an extension of its range.

Field tests conducted in Maine developed a practical fence to exclude green crabs from clam beds and this type of fence is now being used by the state of Maine and by various towns. Control of green crabs by trapping was tested but was found inadequate because of the migration of the crabs. Cooperative studies with the Maine Department of Sea and Shore Fisheries disclosed that the insecticide Lindane is an effective poison for green crabs and a method of preparing and spreading a poisoned bait in the inter-tidal zone was developed. Treatment with poisoned bait reduced the crab population by 85% to 90% in field tests and this method is now in use by the state in areas where lobsters are not present.

The knowledge of the biology of the green crab was greatly increased in an effort to find control methods. Information was obtained concerning age, growth, reproduction, migration, food habits and tolerances to salinity and temperatures.

A study of the parasites of the green crabs was made in an effort to find a biological control method. One parasite (Sacculina) was found in Europe but considered too dangerous to introduce because of the possibility that it might attack other crabs and lobsters.

The knowledge of the biology of the soft shell clam was increased by studies of reproduction, age and growth, relation to bottom types, competitors, etc.

An intensive study of a commercial clamming area in Maine was conducted to develop methods for management. Natural factors were found to be more important in causing changes of abundance of soft clams than commercial digging. The minimum size limit of 2 inches was questioned because of the destruction of undersize clams through breakage and burying during commercial digging. It is considered better to take all clams which were large enough to be used commer-

cially during the harvesting since approximately half of those which are left are destroyed. The Maine Department of Sea and Shore Fisheries is planning this type of management but lacks legislative support at present.

A practical method was devised for collecting soft clam seed which is present in abundance in certain areas in Maine.

Hard Clam Studies — Kingston, Rhode Island

Two methods of harvesting hard clams, hand raking and power dredging, were compared to determine the effect of each on clam populations, on the bottom, and on other associated forms. No reason was found for prohibiting either method under the conditions of the experiment.

The knowledge of the biology of the hard clam was increased through studies of age, growth, reproduction, in relation to hydrographic factors, natural mortalities and the knowledge of some of the factors affecting abundance.

Various devices for collecting seed clams for transplanting were tested including plastic screen, tidal spat trap, pumping water through sand filters, etc. Some of these may have commercial application under certain conditions.

The extent of predation by green crabs and mud crabs was determined through laboratory and field experiments. Predation was found to be an important factor which must be overcome before commercial farming can be successful. Predator control methods including fencing and poisoning have been tested and are ready for practical application.

Studies of the hard clam population in Greenwich Bay, Rhode Island, were designed to develop methods for management of a commercial fishery. These studies include an annual census of a clam population, gathering of catch statistics, hydrographic information, geological studies of the bottom, investigation of spawning, larvae development and setting. The state of Rhode Island is now using the survey methods developed in these studies to obtain information concerning the clam populations in other parts of Narragansett Bay. The results of our studies show that no restriction of catch is required for management of the fishery in Greenwich Bay. Natural factors such as setting affect abundance more than the fishery which takes only one-half, to one-sixth of the legal clams each year. Information obtained in these studies in Rhode Island has proven valuable in the prediction of the effects of proposed hurricane control barriers on the shellfish population on Narragansett Bay.

Clam Investigations — Maryland and Virginia

The importance of predation on the soft clam in Chesapeake Bay and the hard shell clam in Chincoteague Bay is being determined through experiments which are now in progress. Clams protected by a ¼" screen survived but unprotected clams did not, therefore predation is an important factor. Planted seed clams of both species must be protected from predators to yield a commercial crop. Predator control methods developed in New England are being tested to determine their applicability in this area.

Outbreaks of red clams in Chesapeake Bay were reported by the industry during the winter of 1956-57 and investigations are now in progress to determine the cause of this discoloration which adversely affects the marketing of this species. These investigations are being conducted in cooperation with the States of Maryland and Virginia and several other laboratories.

PUBLICATIONS BY CLAM INVESTIGATIONS PERSONNEL

Baptist, John P.

1953. **Record of Hermaphroditic Horseshoe Crab, Limulus polyphemus** L. Breviora, Mus. of Comp. Zool. No. 14, 2 pl. 4 pp. May 28, 1953.

1955. **Burrowing Ability of Juvenile Clams.**
Spec. Scien Rept.: Fish. No. 140, 13 pp. January, 1955.

Glud, John B.

1947.* **Oyster Investigations — Pacific and Olympia Oysters.**
Biol. Div. Dept. Fish. St. of Wash. 1947 Repts. pp 11-14

1947.* **Japanese Clam Industry. Observations on the Japanese Clam Fisheries.**
Biol. Div. Dept. Fish. St. of Wash. 147 Repts. pp 15-24

1949.* **Japanese Methods of Oyster Culture.**
USFWS Sep. No. 235, 11(8):7 pp.

1951. **The Effect of Man on Shellfish Populations.**
Trans. 16th No. Am. Wildlife Conf. March 5-7, 1951, pp. 397-403.

Glude, John B.

1954. **The Effects of Temperature and Predators on the Abundance of the Soft-Shell Clam, Mya arenaria, in New England.**
Trans. Am. Fish. Soc. 84:15-25.

1954. **Survival of Soft-Shell Clams, Mya arenaria, buried at various depths.**
Me. Dept. S. & S. Fish. Res. Bull. No 22, 26 pp December, 1954

1955. **Report of Clam Investigations for Fiscal Year 1955.**
ASMFC No. Atl. Sec. 18th Mtg. Nov. 15, 1955. Appendix 10 pp. 5 figs.

1954. **The Tidal Spat Trap, a New Method for Collecting Seed Clams.** Natl. Shellfish. Assoc. 1954 Proc. pp. 106-115.

1955. **Why Blame the Clam Digger?**
Dividends from Research
Prog. Fish-Cult. p. 94. April, 1955.

1955.* **Report of Atlantic Salmon Investigations for Fiscal Year 1955.**
ASMFC No. Atl. Sec. 18th Mtg. Nov. 15, 1955. Appendix 3 pp.

1955. **New Fence Design Successful in Keeping Out Green Crabs.**
"Along the Clam Flats" Me. Coast Fisherman, p. 22. November, 1955.
"Along the Clam Flats" is name of a regular dept. of the Maine Coast Fisherman each month.

1957.* **Copper, a possible barrier to oyster drills.**
Proc. Nat. Shellfisheries Assoc. 47:73-82.

Glude, John B. and Warren S. Landers

1953. **Biological Effects on Hard Clams of Hand Raking and Power Dredging.**
Spec. Scien. Rept.: Fish. 110, 43 pp. October, 1953.

* Papers which did not result from present Clam Investigations, but are related thereto.

Landers, Warren S.

1954. **Seasonal Abundance of Clam Larvae in Rhode Island Waters,** 1950-52.
Spec. Scien. Rept.: Fish. No. 117, 29 pp. March, 1954

1954. **Notes on the Predation of the Hard Clam, Venus mercenaria, by the Mud Crab, Neopanope texana.**
Ecology, 35(3):1. July, 1954.

Moulton, James M. and Gareth W. Coffin

1954. **The Distribution of Venus larvae in Orr's Cove Plankton over the Tidal Cycle and During the summer and Early fall of 1953.**
Me. Dept. S. & S. Fish. Res. Bull. No 17, 55 pp February, 1954.

Smith, Osgood R.

1952. **The Wanderings of Small Clams.**
Natl. Shellfish. Assn. ann. mtg. Aug. 14, 1952, mimeographed.

1953. **Observations on the Rate of Decay of Soft-Shell Clams, (Mya arenaria).**
Ecology 34(3):640-641. July, 1953.

1953. **Notes on the ability of the Horseshoe Crab, Limulus polyphemus, to Locate Soft-Shell Clams, Mya arenaria.**
Ecology 34(3):636-637. July, 1953.

1955. **Movements of Small Soft-Shell Clams, (Mya arenaria).**
Spec. Scien. Rept.: Fish. No. 159, 9 pp. June, 1955

Smith, Osgood R., John P. Baptist and Edward Chin

1955. **Experimental Farming of the Soft-Shell Clam, Mya arenaria, in Massachusetts,** 1949-1953.
Comm. Fish. Rev. 17(6):16. June, 1955.

Spear, Harlan S. and John B. Glude

1957. **Effects of Environment and Heredity on Growth of the Soft Clam, (Mya arenaria).**
Fish. Bull. 114, From Fish. Bull. of USFWS Vol. 57:279-292.

Stickney, Alden P. and Louis D. Stringer

1957. **A Study of the Invertebrate Bottom Fauna of Greenwich Bay, Rhode Island.**
Ecology 38(1):111-122. January, 1957.

Stunkard, Horace W.

1956. **Studies on Parasites of the Green Crab, Carcinides maenas.**
Biol. Bull. 111(2):295. October, 1956.

1957. **The Morphology and Life-History of the Digenetic Trematode, Microphallus similis** (Jagerskiold, 1900) Baer, 1943.
Biol. Bull. 112(2):254-266. April, 1957.

Tiller, Richard E., John B. Glude and Louis D. Stringer

1952. **Hard-Clam Fishery of the Atlantic Coast.**
(Prepared at the request of the ASMFC)
USFWS Sep. No. 323, 14(10):25 pp. October, 1952.

Uzmann, Joseph R.

1951. **Record of the Larval Trematode, Himasthla quissetenis (Miller and Northup, 1926) Stunkard, 1934, in the Clam, Mya arenaria.**
Jour. of Parasit. 37(3):½p. June, 1951.

1952. **Cercariae myae sp. nov., A Fork-Tailed Larva from the Marine Bivalve, Mya arenaria.**
Jour. of Parasit. 38(2):161-164. April, 1952.

1953. **Cercaria milfordensis nov. sp., a Microcercous Trematode Larva from the Marine Bivalve, Mytilus edulis L. with special reference to its Effect on the Host.**
Journ. of Parasit. 39(4): Sec. 1:445-451. August, 1953.

Uzmann, J. R. and A. P. Stickney
1954. **Trichodina myicola n. sp., a Peritrichous Ciliate from the Marine Bivalve, Mya arenaria L.**
Journ. of Protozool. v1, 149-155.

CLAM RESEARCH PROJECT

Other Reports made to the ATLANTIC STATES MARINE FISHERIES COMMISSION by staff members of the U. S. Fish and Wildlife Service, or by Special Committees, and publications issued by the cooperating states

1948-1957

1948 **Report on the Soft-Shell Clam Industry of the East Coast of the United States,** by Harry J. Turner, Jr., Biologist, Woods Hole Oceanographic Institution, presented to Special Committee of Clam Technicians, ASMFC, May 17, 1948.

Further Observations on Predators of the Soft Shell Clam, by Harry J. Turner and John C. Ayers, Woods Hole Oceanographic Institution and Charles L. Wheeler, Mass. Dept. of Conservation, Div. of Marine Fisheries, presented to Committee of Clam Technicians, ASMFC, October 5, 1948.

Methods of Increasing and Maintaining Production of Soft-Shell and Hard-Shell Clams along the Atlantic Coast, John B. Glude, USFWS, Project Director, December 12, 1948.

Report on Investigations of the Propagation of the Soft Shell Clam, Mya Arenaria, Harry J. Turner, December 31, 1948, prepared under contract with Division of Marine Fisheries, Mass. Dept. of Conservation.

1949 **Fish and Wildlife Service Clam Investigations,** by John B. Glude, Chief, a paper prepared by USFWS for National Shellfisheries Assn., June 6, 1949.

Present Status of Fish and Wildlife Service Clam Investigations, Reports by John B. Glude, Dr. Richard T. Tiller, and Dr. Osgood R. Smith, USFWS, to ASMFC, September 29, 1949.

Report on Investigations of Methods of Improving Shellfish Resources of Massachusetts, Harry J. Turner, Jr., Woods Hole Oceanographic Institution, prepared under contract with Div. of Marine Fisheries, Mass. Dept. of Conservation, Dec. 31, 1949.

1950 **The Story of the Maine Clam,** by Robert L. Dow and Dana E. Wallace, Maine Dept. of Sea and Shore Fisheries.

An Investigation of Fresh Clam (Mya Arenaria) Meats with Respect to Criteria of Adulteration by Donald M. Harriman, Maine Dept. of Sea & Shore Fisheries, April, 1950.

Progress Report — Clam Investigations, presented to South Atlantic Section of ASMFC by John B. Glude, USFWS, June 9, 1950.

Third Report on Investigations of Methods of Improving the Shellfish Resources of Massachusetts, by Harry J. Turner, Jr., Woods Hole Oceanographic Institution under contract with Div. of Marine Fisheries, Mass. Dept. of Conservation, Dec. 31, 1950.

1951 **Roster of Biologists Conducting Research on the Soft Clam (Mya arenaria) and Hard Clam (Venus Mercenaria),** USFWS, April, 1951.

Progress Report to North Atlantic Section, ASMFC, by John B. Glude, USFWS, Boston, Mass. June 28, 1951.

Progress Report of Fish and Wildlife Service Clam Investigations to ASMFC by John B. Glude, USFWS, September 6, 1951. Appendix C-Minutes of 10th Annual Meeting.

Progress Report of the Hard Clam Investigation to ASMFC by Dr. R. E. Tiller, USFWS, September 6, 1951. Appendix D to Minutes of 10th Annual Meeting.

A Method of Reducing Winter Mortalities of Quahogs (Venus Mercenaria) in Maine Waters by Robert L. Dow and Dana E. Wallace, Maine Dept. of Sea and Shore Fisheries, Sept. 1951.

Fourth Report on Investigations of the Shellfisheries of Massachusetts by Harry J. Turner, Jr., et al., Woods Hole Oceanographic Institution under contract with Div. of Marine Fisheries, Mass. Dept. of Conservation, Dec. 31, 1951.

1952 **Progress Report on Clam Investigations** to North Atlantic Section of ASMFC by John B. Glude, USFWS, March 10, 1952.

Progress Report of Fish and Wildlife Service Clam Investigations by John B. Glude, USFWS, to North Atlantic and Middle Atlantic Sections of ASMFC, Sept. 5, 1952. Appendices K and L, Minutes of 11th Annual Meeting

Fifth Report on Investigations of the Shellfisheries of Massachusetts by Harry J. Turner, Jr., et al., Woods Hole Oceanographic Institution under contract with Div. of Marine Fisheries, Mass. Dept. of Conservation, Dec. 31, 1952.

Clam Investigations, Annual Report, Fiscal Year 1952 by John B. Glude, Chief, USFWS.

Maine Clam Study, Appendix II to report entitled "An Economic Evaluation of Marine Fisheries affected by Industrial Wastes" by Donald M. Clifford, Phase II Project 52W-16 - prepared for ASMFC in cooperation with the USFWS, issued 1952 by ASMFC members of the Commission and to State Health and Fishery agencies.

Shellfish Survey Methods, by Robert L. Dow, Technical Bulletin No. 1, Maine Dept. of Sea and Shore Fisheries, November, 1952.

1953 **Report on Clam Investigations for Fiscal Year 1953** by John B. Glude, USFWS, to North Atlantic Section of ASMFC, October 9, 1953. Appendix NA-5, Minutes of 12th Annual Meeting.

Report of Soft Clam Investigations for Fiscal Year 1953, by John B. Glude, USFWS, to North Atlantic Section, ASMFC, October 9, 1953. Appendix NA-6, Minutes of 12th Annual Meeting.

Report of Hard Clam Investigations for Fiscal Year 1953, by John B. Glude, USFWS, to North Atlantic Section, ASMFC. Appendix NA-7, Minutes of 12th Annual Meeting.

Sixth Report on Investigations of the Shellfisheries of Massachusetts, by Harry J. Turner and J. Arthur Posgay, et al., prepared under contract with Div. of Marine Fisheries, Mass. Dept. of Conservation.

1953 **Dermititis Producing Schistosome Which Causes "Clam Diggers Itch" Along the Central Maine Coast,** by Carl J. Sinderman, Phd., Dept. of Sea and Shore Fisheries and Dept. of Biology Brandeis University, and Richard F. Gibbs, Dept, of Zoology, U. of Mass., Research Bulletin No. 12, Maine Dept. of Sea and Shore Fisheries.

1954 **Report of Hard Clam Investigations** by Louis D. Stringer, USFWS, to North and Middle Atlantic Sections, ASMFC, October 4, 1954, Appendix NA-MA-1, Minutes of 13th Annual Meeting.

Report of Soft Clam Investigations, by Walter W. Welch, USFWS, to North Atlantic Section, ASMFC, October 5, 1954. Appendix NA-1, Minutes of 13th Annual Meeting.

Preliminary Experiments in the Use of Ground Controlled Aerial Photography in Intertidal Hydrographic Survey, by Robert L. Dow, Maine Dept. of Sea and Shore Fisheries. "Proc. Nat. Shellf. Assn., Vol. 45 (1954) pp. 199-208."

The Use of Equipment and Techniques in Applied Shellfish Management, by Dana E. Wallace, Maine Dept. of Sea and Shore Fisheries. "Proc. Natl. Shellf. Assoc. Vol. 45 (1954) pp. 209-211."

Growth Studies in the Quahog (Venus Mercenaria) by Alton H Gustafson, Bowdoin College, and Maine Dept. of Sea and Shore Fisheries. "Proc. Natl. Shellf. Assoc. Vol. 45 (1954) pp. 140-150."

The Seed Quahog Dredge, Venus M. by Robert L. Dow and Dana E. Wallace — Fisheries Circular No. 15, Maine Dept. of Sea and Shore Fisheries. August, 1954.

Variations in Total Solids of the Soft Clam (Mya Arenaria) by Donald M. Harriman, Research Bulletin No. 23, Maine Dept. of Sea and Shore Fisheries. Dec., 1954.

1955 **Fifth Conference on Clam Research,** Boothbay Harbor, Maine. March 1-3, 1955.

Natural Redistribution of a Quahog Population by Robert L. Dow and Dana E. Wallace, Maine Dept. of Sea and Shore Fisheries. — Science Oct. 7, 1955, Vol. 122. No. 3171, pp. 641-642.

1956 **The Hardshell Clam Fishery of Maryland Waters,** by F. W. Seiling, Maryland Dept. of Research and Education in Tidewater News, Vol. 12, No. 10 Supplement No. 9, March, 1956.

1957 **The Maine Clam, Mya arenaria,** by Robert L. Dow and Dana Wallace, Maine Dept. of Sea and Shore Fisheries, A Bulletin of the Dept., April, 1957.

Clam and Chesapeake Oyster Investigations 1957-58, by John B. Glude, USFWS, to ASMFC, September 26, 1957. Appendix 13, Minutes of 16th Annual Meeting.

Report on Clam Investigations; by John B. Glude, USFWS, to North Atlantic Section of ASMFC. Appendix NA-5, Minutes of 16th Annual Meeting.

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Some Trematodes of Fishes from the Central Equatorial Pacific

EDWIN S. IVERSEN[1] and EARL E. HOVEN[2]

THIS REPORT is based on a collection of trematodes from marine fishes captured in the vicinity of the Line Islands. All the trematode species listed are believed to constitute first records from this area, and some are first reports from new hosts. Collections were made in 1955 during exploratory tuna fishing by trolling and longlining. These fishing surveys were carried out by Pacific Oceanic Fishery Investigations (POFI), a branch of the U. S. Fish and Wildlife Service, as one phase of a program designed to determine the distribution and abundance of tunas in the Pacific. The Line Islands from which this material was collected are: Christmas, Fanning, Washington, and Palmyra islands, and Kingman Reef. They extend in a northwesterly direction from 2° N. latitude, 157° W. longitude to 6° N. latitude, 163° W. longitude.

All specimens, except the hemiurids, were identified through the kind efforts of Dr. Harold W. Manter, Department of Zoology, University of Nebraska. Unfortunately facilities were not available aboard ship for proper preservation of such material; as a result many of the specimens were identified with difficulty and some could not be accurately identified. Dr. Donald C. Matthews, Department of Zoology, University of Hawaii, very kindly provided sections of the encysted didymocystid included herein. Thanks are extended to E. Dixon Stroup, POFI, for making the photographs used in this report. All collections have been deposited in the U. S. National Museum.

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Order MONOGENEA

Family MICROCOTYLIDAE

Neothoracocotyle acanthocybii (Meserve, 1938)

SYNONYMS: *Gotocotyla acanthocybii* Meserve, 1938.

HOST: Wahoo, *Acanthocybium solandri* (Cuvier and Valenciennes).

LOCATION: Between gill filaments.

LOCALITY: Kingman Reef, 6° 20′ N., 162° 30′ W.

SPECIMENS: USNM Helm. Coll. No. 38132.

PREVIOUSLY REPORTED HOSTS AND LOCALITIES: *Acanthocybium solandri* from the Galapagos Islands.

DISCUSSION: Since these parasites are located between the gill filaments, they are found only by rather close scrutiny. Other duties while at sea prevented a careful record of the number of infected fish. The number of worms per host is probably large and the rate of infestation high. Hargis (1956), who has erected the genus *Neothoracocotyle*, reported the new combination.

Family CAPSALIDAE

Capsala poeyi (Vigueras, 1935) Price, 1938

SYNONYMS: *Tristomum poeyi* Vigueras, 1935.

HOST: Black marlin, *Makaira ampla*[3] (Poey).

LOCATION: Outside surface on isthmus and second dorsal fin.

LOCALITY: 04° 48′ N., 160° 37′ W. (vicinity of Washington Island).

[3] Identification of the Pacific *M. ampla* was based on an unpublished key provided by Dr. William F. Royce. As this paper goes to press, it is apparent that there is considerable disagreement concerning the classification of the marlins.

SPECIMENS: USNM Helm. Coll. No. 38131.

PREVIOUSLY REPORTED HOSTS AND LOCALITIES: Reported from the same species of host off Havana, Cuba, by Vigueras (1935).

Capsala biparasitica (Goto, 1894) Price, 1938

SYNONYMS: *Tristoma biparasitica* Goto, 1894.

HOST: Yellowfin tuna, *Neothunnus macropterus* (Temminck and Schlegel).

LOCATION: Firmly attached to carapace of copepods found in gills.

LOCALITY: 02° 14′ N., 159° 59′ W. (vicinity of Christmas Island).

SPECIMENS: USNM Helm. Coll. No. 38134.

PREVIOUSLY REPORTED HOSTS AND LOCALITIES: Goto collected this species of trematode from a copepod (*Parapetalus* sp.) on *Thynnus albacora* from Misaki, Japan.

DISCUSSION: The copepod involved in the present record is *Elytrophora* sp. A comparison of these host records is of particular interest because the trematode is a hyperparasite and because in each collection both the copepod hosts are caligid copepods and the fish hosts are closely related.

Family HEXASTOMATIDAE

Hexostoma grossum (Goto, 1894) Sproston, 1946

SYNONYMS: *Hexacotyle grossa* Goto, 1894.

HOST: Bigeye tuna, *Parathunnus sibi* (Temminck and Schlegel).

LOCATION: On gills.

LOCALITY: 02° 45′ N., 158° 05′ W.

SPECIMENS: USNM Helm. Coll. No. 38133.

PREVIOUSLY REPORTED HOSTS AND LOCALITIES: On gills of *Thynnus* sp. from Misaki, Japan (Goto, 1894); type host corrected to *Parathunnus sibi* and reported on gills of *Katsuwonus vagans* and *Thunnus orientalis*, and on *Seriola quinqueradiata* from Japan (Ishii and Sawada, 1938).

Order **DIGENEA**

Family HEMIURIDAE

Hirudinella marina Garcin, 1730

SYNONYMS: Nigrelli and Stunkard (1947) include a very lengthy list of possible synonyms of this species.

HOST: Yellowfin tuna, *Neothunnus macropterus* (Temminck and Schlegel).

LOCATION: In stomach.

LOCALITY: 06° 20′ N., 162° 30′ W. (vicinity of Kingman Reef).

PREVIOUSLY REPORTED HOSTS AND LOCALITIES: Nigrelli and Stunkard (1947) include a long list of hosts, mostly of scombriform fishes, including *N. macropterus* from C. San Lucas, Lower California, Pacific.

DISCUSSION: In the course of the examination of stomach contents of yellowfin and bigeye tuna from the central Pacific, King and Ikehara (1956) encountered large muscular trematodes. They report an infection rate of 32 per cent for 166 bigeye and 26 per cent for the 439 yellowfin they examined. Since Nigrelli and Stunkard recognize only two species of *Hirudinella*, one in the wahoo, *H. ventricosa*, and one in other hosts, *H. marina*, it is very likely that these worms belong to the latter species.

Hirudinella ventricosa Pallas, 1774

SYNONYMS: Nigrelli and Stunkard (1947) list nine possible synonyms.

HOST: Wahoo, *Acanthocybium solandri* (Cuvier and Valenciennes).

LOCATION: Stomach.

LOCALITY: Christmas, Fanning, Washington, Palmyra islands, and Kingman Reef.

PREVIOUSLY REPORTED HOSTS AND LOCALITIES: *Acanthocybium solandri* in the Atlantic and Pacific; from the Pacific it has been reported from Panama, Mexico, Equador, and the Marianas Islands (Nigrelli and Stunkard 1947).

DISCUSSION: Nigrelli and Stunkard (1947) have made a thorough study of this genus and

regard all *Hirudinella* reported from the wahoo as belonging to a single species, *H. ventricosa* Pallas. In an examination of 220 wahoo stomachs from the Line Islands, Iversen and Yoshida (1957) found a 98.2 per cent infection of these parasites. The hosts ranged in size from 108 to 172 cm. and as many as 17 of the worms were found in a single stomach, with 2 per host occurring most frequently.

H. ventricosa may be present elsewhere in the Pacific, for Edmondson (1946) states in respect to the Hawaiian region, that "An undetermined species of trematode commonly occurs in the stomach of the Ono, *Acanthocybium solandri* (Cuvier)." These flukes were about 1 inch long when partially contracted. Kishinouye (1923) in speaking of wahoo from Japan says "A large distomum, about 8 cm. in length, is almost always found in the stomach."

Family DIDYMOZOONIDAE

Didymocystis acanthocybii
Yamaguti, 1938

HOST: Wahoo, *Acanthocybium solandri* (Cuvier and Valenciennes).

LOCATION: Base of gill arches and on operculum.

LOCALITY: Christmas, Fanning, Washington, Palmyra islands, and Kingman Reef.

SPECIMENS: USNM Helm. Coll. No. 38171.

PREVIOUSLY REPORTED HOSTS AND LOCALITIES: At base of gill arch of *Acanthocybium sara* (Lay et Bennett); Pacific, Japan, Yamaguti (1938).

DISCUSSION: Of the 104 wahoo examined, 53 revealed conspicuous cysts of this parasite (Fig. 1). The fish ranged in size from 86 to 174 cm., and specimens of all sizes within this range were found to be infected. Figure 2 shows the relationship of the paired worms within the cyst.

Didymocystis sp.

HOST: Yellowfin tuna, *Neothunnus macropterus* (Temminck and Schlegel).

LOCATION: On gill filaments.

LOCALITY: 00° 28′ N., 157° 48′ W.

SPECIMENS: USNM Helm. Coll. No. 38172.

DISCUSSION: The condition of specimens does not permit identification, but they resemble *D. wedli* Ariola, 1902, more closely than others. The infection rate of yellowfin is probably not high.

FIG. 1. Photograph of encysted *Didymocystis acanthocybii* on the side of the head of a wahoo (gill cover removed).

DISCUSSION

Concomitant studies of hosts and parasites from different geographic areas have been reviewed by Metcalf (1929) and Manter (1955), who have presented considerable evidence that parasites reflect the distribution and way of living of their hosts. A basic problem in the study of some pelagic fishes is to determine whether the population of each important species is continuous throughout its range or whether it is composed of a number of independent or semi-independent

units. In this connection these records, especially of Monogenea which are host specific, are of interest. *Capsala biparasitica* from yellowfin tuna in Japan and the Line Islands, *Hexastoma grossum* from bigeye in Japan and the Line Islands, *Neothoracocotyle acanthocybii* from wahoo in the Line and Galapagos islands, and *Capsala poeyi* from the black marlin in the Atlantic and Pacific, all suggest that these stocks of fish are not, or were not, completely independent.

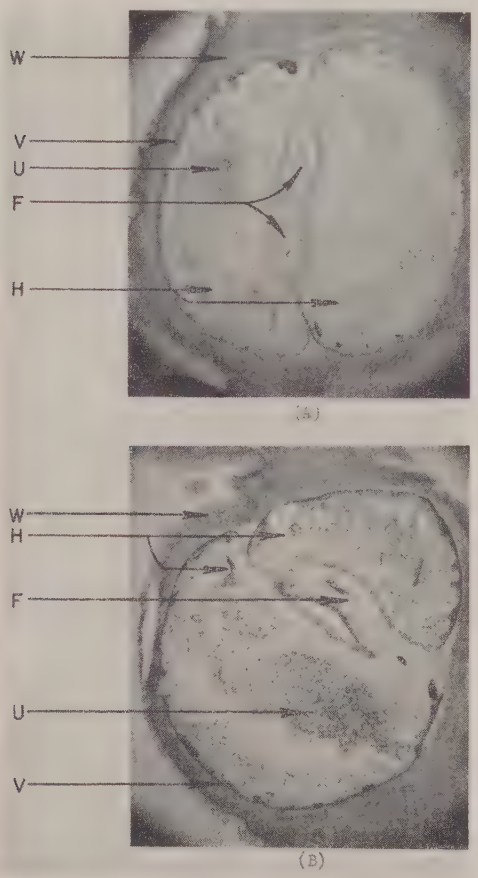

FIG. 2. *Didymocystis acanthocybii*. (A) Photomicrograph of a cross section through two trematodes showing the host tissue (W) surrounding the cyst, the forebodies (F), the hindbodies (H), the uterus (U), and vitellarium (V) of each. (B) Photomicrograph of a section through two trematodes showing the forebody of one in sagittal section. 10 microns.

REFERENCES

EDMONDSON, C. H. 1946. *Reef and Shore Fauna of Hawaii*. Bernice P. Bishop Museum Special Publication 22, iv + 381 pp.

GOTO, S. 1894. Studies on the ectoparasitic trematodes of Japan. *Tokyo Imp. Univ., Col. Sci. Jour.* 12(4): 263–295.

HARGIS, W. J., JR. 1956. Monogenetic trematodes of Gulf of Mexico fishes. Part XII. The family Gastorcotylidae Price, 1943. *Bul. Mar. Sci. Gulf and Caribbean* 6(1): 28–43.

ISHII, N., and T. SAWADA. 1938. Studies on the ectoparasitic trematodes. *Livro Jub. Lauro Travassos*. Pp. 231–243. Rio de Janeiro.

IVERSEN, E. S., and H. O. YOSHIDA. 1957. Notes on the biology of the wahoo in the Line Islands. *Pacific Sci.* 11(4):370–379.

KING, J. E., and I. I. IKEHARA. 1956. A comparative study of the food of bigeye and yellowfin tuna in the central Pacific. *U. S. Fish and Wildlife Ser., Fishery Bul.* 57(108): 61–85.

KISHINOUYE, K. 1923. Contributions to the comparative study of the so-called scombroid fishes. *Tokyo Imp. Univ., Col. Agr. Jour.* 8(3): 293–475.

MANTER, H. W. 1955. The zoogeography of trematodes of marine fishes. *Expt. Parasitology* 4(1): 62–86.

METCALF, M. M. 1929. Parasites and the aid they give in problems of taxonomy, geographical distribution, and paleogeography. *Smithsn. Inst., Misc. Collect.* Vol. 81, No. 8. 36 pp.

NIGRELLI, R. F., and H. W. STUNKARD. 1947. Studies on the genus *Hirudinella*, giant trematodes of scombriform fishes. *Zoologica* 31(13): 185–196.

VIGUERAS, I. 1935. *Tristomum poeyi* n. sp. (Trematoda), parasito de *Makaira ampla* Poey (Pisces). *Nat. Hist. Soc. Cuba, Mem.* 9(1): 43–44.

YAMAGUTI, S. 1938. Studies on the helminth fauna of Japan. Part 21. *Trematodes of Fishes, IV*. 139 pp. Maruzen Co., Tokyo.

THE ROLE OF THE ESTUARY IN THE LIFE HISTORY AND BIOLOGY OF ATLANTIC MENHADEN

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The Role of The Estuary in the Life History and Biology of Atlantic Menhaden

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There is at present a keen interest in estuarine research among marine biologists on the Atlantic Coast of the United States. The reason for this recent attention is the realization that man's activities in this environment may destroy a vital link in the life cycle of many marine organisms which support many of our coastal fisheries. The lives of many of these organisms, therefore, are dependent on the continued existence of this unique environment.

Between Cape Canaveral and Cape Cod there are approximately thirty-eight estuarine systems which are now known to provide an environmental link in the life history and biology of the Atlantic menhaden (*Brevoortia tyrannus*). There is no reason to doubt that most of the numerous unstudied estuaries along the Atlantic Coast also serve the same role. It is for this reason that detailed knowledge of the estuarine environment is essential for understanding the biology of this prolific species.

The findings which are summarized in this paper are based primarily on six year's study of Indian River, Delaware, an estuary located in the central part of the range of Atlantic menhaden. Additional observations over the past three years in thirty-four other estuaries from the Halifax River, Florida to the Sheepscott River, Maine, have furnished comparative and corroborative information.

In discussing the results, we should like to (1) summarize briefly what we know of the relation between the estuary and the events in the life history of Atlantic menhaden, (2) point out how certain physical and biotic features affect the behavior, distribution, and abundance of this species in the estuary, and (3) mention some of the problems concerned with the estuarine phase of our investigations.

The first event in the life history of this species associated with the estuary commences a matter of weeks, or perhaps months, after hatching of the eggs at sea. The larvae occur in large numbers outside the river mouths, and under suitable conditions they enter and become established within. Throughout most of the spawning season they can easily be obtained in large numbers at the river inlets by means of plankton nets suspended in the tidal currents. Hundreds of such collections made during the course of our work have shown conclusively that those made on the flood current consistently yield much greater numbers than those on the ebb. Furthermore, surface tows are much more productive than those made at intermediate depths and on the bottom. Yet the mechanisms controlling the orientations of the larvae which lead to their recruitment into the estuary are not understood. Entering larvae range from about eight to forty-two millimeters in length, but most are around twenty-six millimeters. At this stage they are rather elongated and quite transparent, with black pigment spots prominent on the lower surface of the body and about the head; they are devoid of scales, and the fins are only partially formed.

Entry of the larvae into the estuaries varies in time and duration in different

localities, but it occurs mostly in the late winter and spring months and may continue anywhere from two to seven months in a given locality.

Following their entry into the estuary, the larvae are found congregated near the upstream limits of the tidal zone in groups of many thousands of individuals. Here, and even during their migration from the ocean, they undergo metamorphosis into juveniles. During this transformation the body deepens, scales are laid down, all of the fins become fully differentiated, and the fish take on the color of the adults. The gut becomes highly elongated and convoluted, and the gill rakers, used in filter feeding, become much more numerous. This transformation commences at a body length of about twenty-six millimeters, but is retarded during the winter and early spring months. Larvae entering the estuary during the winter and early spring complete differentiation at a body length of about fifty-five millimeters, while those entering in late spring complete metamorphosis at about forty-two millimeters. As the fish increase in size, schools of the larger individuals spread out from the initial nursery areas and move farther downstream until a size gradient is established over their range of distribution in the estuary. It is of interest to note that this species has been observed schooling at the smallest sizes encountered in these waters.

After spending the summer months in the estuary, the schools of juveniles congregate in larger bodies inside the river mouths and eventually move out into the ocean. Generally, this emigration commences in late August in northern estuaries, while in southern estuaries, it may be delayed into January. At the time of their departure, the juveniles range in size from roughly fifty-two to one hundred and sixty millimeters in fork length.

During the following summer, as one-year olds, they support the bulk of the purse seine fishery along the south Atlantic Coast and in Chesapeake Bay, but large numbers occur in the sounds and rivers from Florida to the North Carolina-Virginia border. Indeed, two-year-old fish often are found in these inland waters. The relative proportion of these age groups which use such areas as post-nursery grounds has not been determined.

At least part of the adult population also utilizes the estuaries within Chesapeake Bay and along the middle Atlantic Coast, apparently for feeding purposes, during the late winter and early spring. They enter and leave these waters throughout the winter, but usually congregate in greatest numbers for a short period in late February and early March, after which time they are largely absent, although abundant along the adjacent coast.

In consideration of some of the specific features of the estuarine environment which relate to the biology of Atlantic menhaden, it would appear that food—its availability and kinds—is perhaps the single most important factor governing the distribution of larvae and juveniles. Examinations of stomach contents of the fish at these stages show that diatoms and holophytic flagellates form the bulk of the ingested material. The shallow waters of the upper tidal areas are particularly rich in these organisms, and here the menhaden are in the greatest abundance throughout the summer and remain latest in the fall. Nutrients essential to plankton growth are in strong supply in such areas, being delivered, in large part, by runoff from the surrounding countryside. The character and quality of the soil within the drainage basin and the extent of agriculture probably have a considerable influence.

Salinity appears to be a rather critical factor in the development and growth of the young fish. Larvae reared through metamorphosis in highly saline waters

at the U. S. Fishery Laboratory, Beaufort, North Carolina, for example, developed abnormalities in body form and structure, while those reared in reduced salinities developed normally. Repeated attempts to transplant larvae and metamorphosing individuals from the low salinity of the upper estuary to the more saline waters of the rearing ponds invariably met with failure. Yet, when such transplants were made several weeks after metamorphosis, they were successful. During March 1958, when prolonged rainfall had reduced the salinity near the Beaufort laboratory to about 10 ‰, larvae and small juveniles occurred in tremendous numbers in the area for the first time in the last four years. Several thousand were successfully established and growing rapidly in the rearing ponds until June, when reduced rainfall and high tides raised the salinity to near-oceanic values, and all juveniles soon died. Similar observations were made under natural conditions in Indian River, Delaware in March 1953 when heavy mortalities and structural abnormalities followed intrusions of highly saline water, occasioned by high tides and persistent, high onshore winds. These findings might be related to the delayed development of the water-balance mechanism of the euryhaline adult; however, they could also simply relate to starvation resulting from poor plankton production in the highly saline water at the times when mortalities were recorded. Histological investigation of the water-balance mechanism during its early development, in the light of the presumed fresh water or anadromous ancestry of menhaden, could be enlightening. Indeed, laboratory experiments for determining the salinity tolerences from the larval through the juvenile stages of development are urgently needed.

Water temperature also is related to certain life history features and behavior patterns of the fish. There appears to be a minimum temperature associated with the occurrence of larvae at the river mouths during winter. Over the past three years, for example, water temperatures below about 3° C at the mouth of Indian River have coincided with an absence of menhaden larvae in our plankton tows. When low temperatures have prevailed over a period of several weeks, we have found a high percentage of structural abnormalities, especially among the larger larvae, once recruitment into the estuary recommenced. Thus, water temperature during the period of entry may be a source of mortality in some years. A heavy winter kill of one-year-old menhaden in the Neuse River, North Carolina in February 1958 was attributed to freezing water temperatures which persisted over a period of two weeks. Also, all young menhaden being reared in the outdoor ponds at Beaufort (ca. 500) were killed during this period.

The fall emigration of juveniles from the estuaries also appears to be directly related to water temperature. Our records from Indian River indicate that it commences when temperatures in the estuary first fall below those of the adjacent ocean. Such a drop may occur in the shallow waters on each cold night after the end of August, each occasion being accompanied by a departure of juveniles. On the other hand, during warm periods in the fall, numerous juveniles reappear in this estuary. Comparisons of size distributions and meristic characters of these late inhabitants have shown that they were not members of the endemic summer population, but probably originated in estuaries north of Long Island and presumably entered the river while migrating southward.

Among the many problems concerned with our estuarine studies, perhaps the most difficult and important of these deal with estimating the relative

strength of a year class while it is still in the estuary and the mortality sustained during its stay in these waters. In attacking these problems, we have worked out techniques at Indian River which have been extended to other locations along the coast. One of these methods, for example, was applied in a number of tributaries from Massachusetts to North Carolina during the past summer. It essentially consists of marking large numbers of individuals by clipping the ventral lobe of the caudal fin and estimating the size of the population in the estuary from the proportion of recaptures in random samples. With this method, if the population chosen is too large, it is impractical to mark enough fish to obtain a reliable estimate. And estuarine populations of menhaden tend to be quite large. In consequence, the marking experiments were restricted to a tributary portion of an estuarine population. The question then arises whether such tributary populations can be found which are sufficiently stable to estimate reliably. That they are appears to be the case in those estuaries consisting of a central bay fed by a number of tributary streams. Earlier it was mentioned that the larvae and metamorphosed juveniles congregate near the upstream limit of tide. Accordingly, the population in an estuary during the early summer has been found to consist of a number of tributary subpopulations which, as the season progresses, partially merge in the lower reaches of the river. Initial attempts to estimate such a tributary population in late spring, when its integrity presumably is greatest, resulted in a high mortality among both marked and unmarked fish. However, by closing off a tributary creek with either a wall of netting, or a semi-permanent fence of galvanized hardware cloth, the contained subpopulation could be marked at such time when its constituent individuals were large enough to minimize mortality from capture and marking. Results have shown that the latter procedure not only results in virtually no mortality, but it can be applied in a large number of tributaries along the coast for the purpose of establishing an index of the relative abundance of a year class. The reliability of this method is being assessed from the results of other comparative methods of estimation which were conducted in certain areas; these include: (1) catch depletion from intensive seining, (2) school censusing, both from the surface and from the air, and (3) an absolute count of the fish in the fenced off tributary by trapping all individuals as they leave. Since some phases of this work are still going on, an evaluation of the results is precluded. If reliable, the marking method eventually may furnish a means for comparing the relative abundance from one year to another. Ultimately, of course, its reliability will be determined by its relation to the abundance of a given year class when the fish enter the commercial fishery as one-year-olds.

Further efforts along these lines have been concerned with the use of fluorescein dyes and radioactive tags. If practical means of marking and recovering larval and juvenile menhaden can be accomplished, by one or both of these techniques, they not only will be useful for population estimates, but also will yield information on the migration of the fish. Results of some of the laboratory work now await further trials. Suffice it to say that both methods offer promise of success.

A measure of natural mortality sustained during the estuarine phase of the life of Atlantic menhaden is, of course, entirely contingent upon reliable population estimation methods. The fin-clipping method, mentioned in the foregoing, indicates the mortality sustained only during the last few months that the

fish occupy the estuary. However, if we can achieve an estimate of mortality which would cover the entire period that the fish occur in these waters, it would provide the information necessary for determining whether conditions in the estuary are responsible for the success of a year class. Once we know the stages in the life history which sustain the greatest mortality, we can direct attention to the causative factors. The marking of entering larvae by means of a flourescein dye renders solution of this problem less remote.

A final problem deals with the need for a realistic evaluation of the importance of the estuary in the face of man's growing use of this environment. In its virgin state, an estuary is entirely kinetic, the result of natural influences, such as the shape of the basin (and its drainage system), wind, tides, rainfall, sunlight, temperature, etc. It fluctuates around its mean conditions, shifting little geographically, and remains, in most cases, a productive aquatic environment, only to the extent that these influences tend to balance one another quite rapidly. Even violent phenomena, such as hurricanes, floods, and droughts, which are often catastrophic to organisms in the estuary, are of relatively brief duration and have only an immediate, direct effect. Furthermore, natural catastrophies seldom influence more than a small part of the extensive range of an animal species such as Atlantic menhaden.

Man's activities are a striking exception. When he, at any time, alters the inherent balance of the estuary, he can never be quite certain of the result. Dredging, filling, marsh drainage, impoundments, recreational developments, and pollution are enduring influences seemingly destined to occupy all the estuaries on the Atlantic Coast. It, indeed, would be difficult to imagine an activity more purposefully devised to quickly affect all estuaries than the mosquito spraying program on the coastal marshes. The changes wrought in the estuary by such activities often are subtle, and it becomes especially difficult to measure both their immediate and long-term effects. Obvious, widespread, deleterious effects are not yet common, but one example of their far-reaching implications perhaps will suffice. Last summer we were called upon to investigate a mass mortality of young menhaden in a southern river which has been developed for summer recreational purposes. The number of dead fish which littered the beaches (to a depth of several feet in some areas) was estimated to have exceeded the total number of fish caught during the fall menhaden fishing season off North Carolina in 1957. The cause of this particular mortality was traced to industrial pollution. Such incidences of man's influence on the estuary are becoming more evident as his number increases.

The solution of these and related problems is not simple, but laboratories devoted to estuarine research along the Atlantic Coast are making headway. For only by continued, intensive study of the inherent and induced features of the estuary and their interaction can we, in time, hope to understand how they relate, not only to the biology of Atlantic menhaden, but also to all organisms associated with this unique environment.

Haddock Scale–Otolith Comparisons[1]

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ABSTRACT

Comparisons of scale and otolith age readings have been made for haddock from Subareas 4 and 5 of the ICNAF Convention Area. Percentage of disagreeing readings increases with increasing average age of the fish. In cases of disagreement, scale ages are consistently lower than otolith ages for fish above about 7 years of age in Subarea 5, and for practically all ages in Subarea 4. Variation in results from the 2 methods produces differences in relative strengths of year-classes but has little effect on growth rates.

INTRODUCTION

A preliminary comparison of haddock scale and otolith age readings was carried out by the Fisheries Research Board of Canada's Biological Stations at St. John's and St. Andrews in 1950 (Kohler *et al.*, 1958). Scales from the International Commission for the Northwest Atlantic Fisheries Subareas 3 and 4 fish were read at St. John's while corresponding otoliths were read at St. Andrews. For a total of 576 individuals, 464 (81%) of the corresponding readings agreed. The majority of disagreements were found in readings for old fish, with a tendency toward lower scale than otolith age readings for these individuals.

The present study deals with further comparisons of scale and otolith readings made in 1952, 1953, and 1954 for haddock from Subareas 4 and 5. Scales from these fish were read by United States biologists at Woods Hole and the otoliths were read by St. Andrews personnel. In a total of 764 comparisons, scale and otolith readings agreed in 476 (62%) of the cases. The lower percentage of agreement for this group of readings led to a more detailed analysis of the data arising from them.

METHODS

Sampling

Ten samples were examined for which scales and otoliths were taken from each haddock. Of these samples, 5 were taken by Woods Hole personnel from Subarea 5 fishing grounds and 5 were taken by Canadians from Subarea 4. The map in Fig. 1 shows the distribution of samples on the fishing grounds of Subareas 4 and 5. A list of the samples by number, date, and fishing area can be seen in Table I. The size of the samples varied from 39 to 102 fish.

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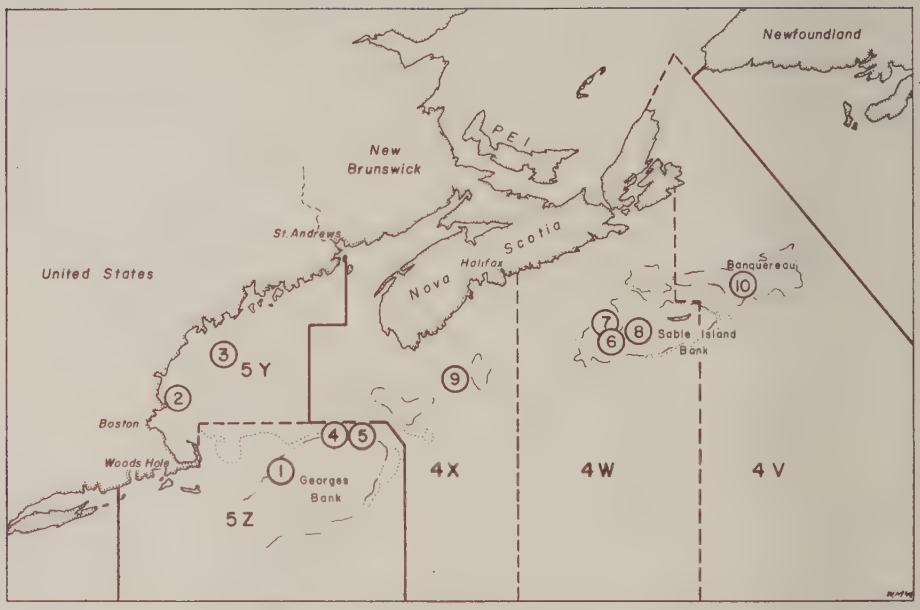

FIG. 1. Map showing locations from which haddock scale-otolith samples were taken. Sample code numbers are in circles. ICNAF subdivisions are outlined.

TABLE I. Results of scale-otolith comparisons for individual samples, 1952–1954.

Sample No.	Month and year taken	Area	ICNAF Subdiv.	Number of fish in sample	Mean age of samples in years			Agreement per sample	
					Scales	Otoliths	Av.	SA 5	SA 4
								%	%
9	Apr./54	Little LaHave	4X	39	6.56	6.72	6.64	...	54
6	Feb./54	Western Bank	4W	60	6.57	6.60	6.58	...	48
8	Apr./54	Sable Island Bank	4W	41	6.02	5.98	6.00	...	51
7	Mar./54	Western Bank	4W	59	5.59	5.97	5.78	...	56
5	Dec./53	Georges Bank	5Z	102	5.65	5.66	5.66	46	...
4	Sept./53	Georges Bank	5Z	99	5.16	5.56	5.36	60	...
3	June/53	Gulf of Maine	5Y	99	5.32	5.26	5.29	66	...
10	Aug./54	Banquereau	4V	65	4.78	5.17	4.98	...	60
2	Apr./53	Gulf of Maine	5Y	100	4.96	4.86	4.91	78	...
1	Dec./52	Georges Bank	5Z	100	2.36	2.35	2.36	90	...

AGE DETERMINATION

The examination of haddock scales was carried out as follows: As described by Arnold (1951), scale impressions were made on cellulose strips and the impressions were projected at a magnification of 40×. Ages were determined by counting the number of zones of closely spaced, dark circuli which are laid down during winter months. These zones are separated by areas of widely spaced, lighter circuli which are formed in the summer months.

Otoliths were fractured across an interruption in the longitudinal groove, the *sulcus acusticus*, on the convex side. The resulting pieces were imbedded in a cube of modelling clay, the surfaces of the fractures being set flush with the upper surface of the cube. They were covered with a few drops of 50% glycerin solution and examined under reflected blue light through a stereoscopic microscope (9×). Hyaline (winter) zones, separated by opaque (summer) zones, were counted to give the age of the fish.

RESULTS OF COMPARISONS

Samples in Table I are arranged in order of descending average age. A comparison of the 5 samples with the higher average ages and those with lower average ages shows better percentage agreement between scale and otolith readings in the latter group. This also holds true within each subarea. Combination of all samples gives 62% agreement for 764 individual scale and otolith readings.

TABLE II. Summary of scale and otolith readings for Sub-area 5 haddock. Dashed lines enclose all fish which were aged 2 or 3 by either method (refer to Table IV). Boxes enclose the numbers of scale and otolith readings in agreement.

Otolith Age Reading \ Scale Age Reading	1	2	3	4	5	6	7	8	9	10	11	12
1												
2		75	7									
3		4	15	8	2	1						
4			14	76	17	1	1					
5			5	19	123	10	1					
6			1		9	9	5	5				
7					1	14	21	10				
8					2	1	8	9	1		1	
9						1	4	7	3			
10								2				
11								2		1	1	
12									1			1

In order to show more specific trends in scale–otolith comparisons the data are divided into 2 groups, one containing all Subarea 5 samples and the other containing all Subarea 4 samples. Table II shows the relationship of scale and otolith readings from Subarea 5. In this group of 500 individuals, 67% of the scale and otolith readings agree, 19% of the scale readings are lower than the otolith readings, and 14% of the otolith readings are lower than the scale readings. In Table III data for Subarea 4 fish are plotted in the same way. Here, only

TABLE III. Summary of scale and otolith readings for Sub-area 4 haddock. Boxes enclose the numbers of scale and otolith readings in agreement.

Otolith Age Reading \ Scale Age Reading	1	2	3	4	5	6	7	8	9	10	11	12	13
1													
2													
3													
4			2	9	5								
5			1	28	78	9	2	1					
6					9	19	3	1					
7						20	25	14		1			
8						3	11	10	1				
9							3	2	1				
10							1	1		1			
11								1			1		
12													
13										1			

54% of the readings are in agreement; 32% of the scale readings are lower than the otolith readings and 14% of the otolith readings are lower than the scale readings.

Data from the 2 areas have been broken down by age groups and trends in disagreement tested statistically. Ages less than 10 are combined by twos in order to dampen the effect of disagreeing readings from a strong age group on disagreements from an adjacent weak age group. Because of relatively small numbers of old fish, individuals aged 9 to 12 by either method are combined for testing purposes.

The statistical test consists of first summarizing for each group considered the numbers of individuals with scale age lower than otolith age and with otolith age lower than scale age. The resulting numbers are then tested against the hypothesis that they are equal (i.e., that they do not differ significantly from their mean) by calculating chi-square values in the usual manner. When the numbers in either group fall below 5, Yates' correction is applied (cf. Snedecor, pp. 22, 193). As an example, where scale and otolith ages are 2 and 3 (within dotted cross in Table II) calculations were as follows:

	No. of fish
Scale age lower than otolith age	24
Otolith age lower than scale age	18
Mean =	21

$$\chi^2 = \frac{(24-21)^2}{24} + \frac{(18-21)^2}{18} = 0.875.$$

All other groups considered were treated in the same manner. For each chi-square value the probability of obtaining as large or a larger value was looked up in the tables of chi-square (cf. Snedecor, p. 190) interpolating the values to the nearest percentage for small probabilities. The results for Subareas 5 and 4 are tabulated in Tables IV and V, respectively. The differences are interpreted as significant at the 5% level.

Examination of Table IV indicates no statistically significant difference in amounts of the 2 types of disagreement up to about 7 years of age for Subarea 5 haddock. The 8- and 9-year-old group also does not show a difference significant at the level which we have chosen. However, it is evident that in ages over 7 years the otoliths tend to give higher readings than the scales. This is indicated by the chi-square probability figures.

TABLE IV. Comparison of scale and otolith age reading disagreements in Sub-area 5 using the chi-square test.

Scale or otolith age	Number of disagreements	Chi-square value	Probability of a larger chi-square value	Predominant type of disagreement
2 and 3	Sc < Ots 24			
	Ots < Sc 18	$\chi^2 = 0.875$	0.50	No significant difference
3 and 4	Sc < Ots 43			
	Ots < Sc 37	$\chi^2 = 0.453$	0.50	,,
4 and 5	Sc < Ots 50			
	Ots < Sc 41	$\chi^2 = 0.899$	0.50	,,
5 and 6	Sc < Ots 53			
	Ots < Sc 43	$\chi^2 = 1.053$	0.50	,,
6 and 7	Sc < Ots 39			
	Ots < Sc 34	$\chi^2 = 0.344$	0.70	,,
7 and 8	Sc < Ots 41			
	Ots < Sc 24	$\chi^2 = 4.773$	0.03	Sc < Ots
8 and 9	Sc < Ots 28			
	Ots < Sc 18	$\chi^2 = 2.282$	0.14	No significant difference
9 to 12	Sc < Ots 18			
	Ots < Sc 3	$\chi^2 = 16.800$	0.01	Sc < Ots

Examination of Table V reveals significant differences in all ages except 8 and 9 for Subarea 4 haddock. In all cases showing differences the scale < otolith group is predominant.

TABLE V. Comparisons of scale and otolith age reading disagreements in Sub-area 4 using the chi-square test.

Scale or otolith age	Number of disagreements	Chi-square value	Probability of a larger chi-square value	Predominant type of disagreement
4 and 5	Sc < Ots 40			
	Ots < Sc 17	$\chi^2 = 11.086$	0.01	Sc < Ots
5 and 6	Sc < Ots 61			
	Ots < Sc 21	$\chi^2 = 25.604$	0.01	Sc < Ots
6 and 7	Sc < Ots 47			
	Ots < Sc 30	$\chi^2 = 3.946$	0.05	Sc < Ots
7 and 8	Sc < Ots 42			
	Ots < Sc 23	$\chi^2 = 6.073$	0.02	Sc < Ots
8 and 9	Sc < Ots 21			
	Ots < Sc 17	$\chi^2 = 0.425$	0.70	No significant difference
9 to 13	Sc < Ots 10			
	Ots < Sc 2	$\chi^2 = 6.189$	0.02	Sc < Ots

Effect of Differing Age Readings on Parameters

The rather extensive disagreement between methods led us to examine its effect on the relative strengths of year-classes and growth.

Age compositions derived from otolith and scale data are plotted in Fig. 2 for Subareas 4 and 5. The populations of fish found in Subarea 5 consist mainly of fish which are 5 years of age or less, and the relative strengths of year-classes agree quite well. Here, overall agreement between methods is 67% and no significant bias in type of disagreement is evident until the fish are about 7 years

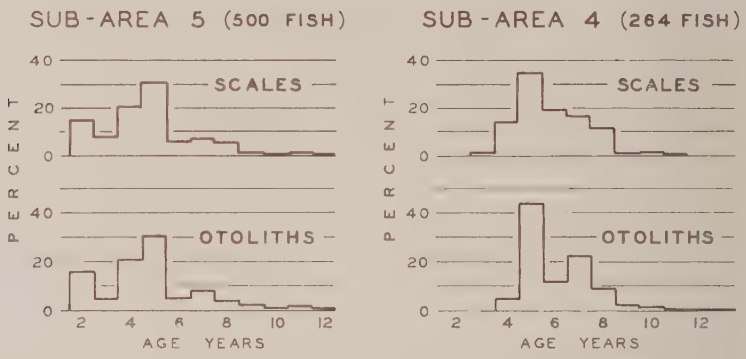

Fig. 2. Haddock age compositions by sub-area and aging method.

old. In Subarea 4 relative strengths of year-classes do not agree well between the two methods. Here, overall agreement is only 54%, and in the majority of cases of disagreement scale readings are lower than otolith readings. One of the effects here is to artificially increase the numbers of 4- and 6-year-olds (the smaller year-classes) and lower the numbers of 5- and 7-year-olds (the larger year-classes) in the scale age composition as compared to the otolith age composition. With consistently lower scale than otolith readings, mortality rates computed from scale ages would be higher than those from otoliths.

Growth data for each sample are plotted in Fig. 3 as average lengths for each age. Where points represent means from 10 or more fish, the average lengths for that age derived from each method lie close together. In 17 out of 19 cases where this occurs, the scale mean length is slightly higher than that found by means of the otolith readings. However, the displacement is usually only a small fraction of a year's increment, and since most of the displacements are in one direction, there is little effect on the estimated growth rates.

Gulland (1955) has published some theoretical considerations of the effects of errors in age readings on various parameters. He has shown that as long as errors do not change greatly from one age to the next, the effect on growth and survival rates is not great. However, such errors will alter the age distribution. Apparently this is what has happened in the tests conducted here.

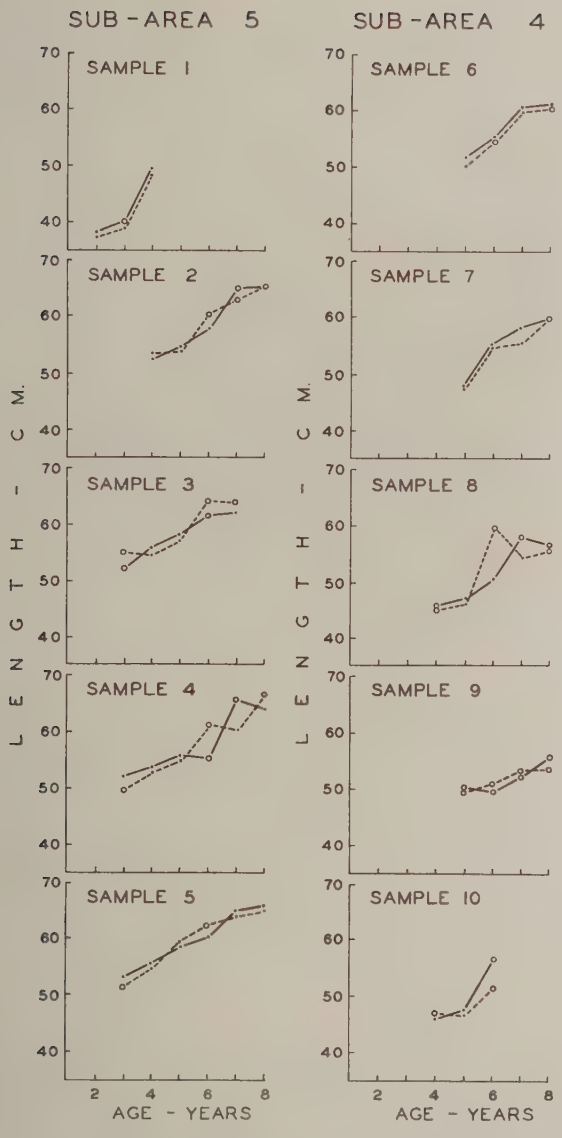

FIG. 3. Haddock growth data by sample and aging method. A solid dot indicates an average from 10 or more fish; an open circle indicates an average for less than 10 fish.

Solid lines: growth from scale readings.

Broken lines: growth from otolith readings.

DISCUSSION

Re-examination and comparison of some of the disagreeing material show that many of the discrepancies are due to differing interpretation of corresponding zones which appear in both the scales and otoliths. Scale readers further point out that the clarity of annuli in the edges of scales diminishes in older fish. A related point to be considered is that the otolith readers were unfamiliar with the annular patterns in material from the relatively young Subarea 5 fish. Scale readers were in the same position regarding interpretation of rings in the scales of older Subarea 4 fish. The greater average age of fish in Subarea 4 tends to provide greater opportunity for conflicting age readings.

Comparison of Tables IV and V indicates that for Subarea 5 haddock there are no statistically significant differences in scale or otolith ages up to an age of about 7 years, from which point scale readings are consistently lower than otolith readings. However, for Subarea 4 where commercial sizes of haddock are older, scale readings are significantly lower than otolith readings at almost all ages sampled. Since re-examinations of disagreeing material showed that otoliths seemed to be a more promising tool for aging old fish than scales, further tests have been carried out to establish the validity of the otolith method. This work will be the subject of another paper. Woods Hole biologists are at present carrying out a further critical review of the scale method, which has been the only one used in Subarea 5. This study will be reported on in the future.

ACKNOWLEDGMENTS

Thanks are due to Dr. W. R. Martin for his advice as to the direction of our efforts and to Mr. J. E. Paloheimo for suggesting statistical tests. Mrs. J. Stuart carried out the preliminary otolith readings for samples 1 to 3 and Mr. A. C. Jensen read the scales for samples 7 to 10.

REFERENCES

Arnold, E. L., Jr. 1951. An impression method for preparing fish scales for age and growth analysis. *Progressive Fish-Culturist*, **13**(1): 11–16.

Gulland, J. A. 1955. Estimation of growth and mortality in commercial fish populations. *Great Britain, Min. Agric. Fish. Food, Fish. Invest.*, Ser. II, **18**(9), 46 pp.

Kohler, A. C., W. Templeman, J. R. Clark and A. C. Jensen. 1958. Haddock scale-otolith comparisons. Summary for Biarritz Report of Committee on Research and Statistics of I.C.N.A.F. In press.

Snedecor, G. W. 1946. Statistical methods. Collegiate Press, Ames, Iowa.

AGE AND GROWTH OF THE AMERICAN SHAD, FROM THREE ATLANTIC COAST RIVERS

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ABSTRACT

Study of age and rate of growth of the American Shad *(Alosa sapidissima)* in three southeastern coastal rivers (St. Johns River, Florida, Neuse River, North Carolina and Susquehanna River, Maryland) shows similar growth rate in these three streams and a body-scale relationship that can be described by the parabolic equation, $y = 22.58x^2 + 34.96x + 0.41$. When allowance is made for differences in aging methods, it appears that growth was similar to that reported in the literature for shad from two Canadian populations. Little difference was found in length of males and females of the same age but males matured earlier and were generally more abundant in commercial catches. The annulus appears to be a true year-mark on scales of shad spawning for the first time and results from aging of these fish from scales are not in conflict with known facts about the shad. Spawning marks are considered to be year-marks for "repeater" shad, that is, shad that have spawned more than once, but this has not been validated.

INTRODUCTION

Production of shad *(Alosa sapidissima)* along the Atlantic coast has declined sharply since 1896. At that time, the catch was 50 million pounds as compared to 17 million pounds in 1946 and 8 million pounds in 1950. In 1950, the U. S. Fish and Wildlife Service began an Atlantic-coast shad investigation initiated by the Atlantic States Marine Fisheries Commission. The purposes of this investigation are to determine the causes of the decline of shad since the turn of the century and to suggest measures for the restoration of the shad populations to their former levels of abundance. The ultimate objective is the suggestion of management measures for maximum sustained yields from each population.

This paper is concerned with age and growth of shad from the St. Johns River, Florida; the Neuse River, North Carolina; and the Susquehanna River, Maryland and with the validation of the annulus as a true year mark for shad.

Leim (1924) studied age and rate of growth of shad as part of life history studies of this species in Canadian waters. He determined age from counts of annuli on scales. Borodin (1925) counted the transverse grooves

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on the scales and divided by two to determine age in years. Barney (1925) confirmed Borodin's method by the study of otoliths. Greely (1937) questioned Borodin's method. His annuli counts agreed closely with those of Leim. Cating (1953) used annuli to determine age and separated true from false annuli, to the fourth annulus, by a method of transverse groove counts. By using easily-read scales, he found that the number of transverse grooves within each annulus was quite constant in all fish examined.

American shad are anadromous and spawn during late winter (February-March) in the St. Johns River and in the spring (April-May) in the Neuse and Susquehanna Rivers. The young-of-the-year fish remain in fresh or brackish water until fall (October-November) when they migrate to the sea. Here they stay from two to five years before returning to fresh water to spawn for the first time.

Prior to the initial spawning run, true annuli are formed each year on shad scales. During the initial and subsequent runs, spawning marks are formed. These marks probably are true year marks (Cating, 1953) but differ in form from the pre-spawning annuli. In the present paper annuli are denoted by Roman numerals, and spawning marks by Arabic numerals. Since all adult shad were caught during the spawning season, the edge of the scale was designated as the location of a spawning mark. Age class of a shad is denoted by two numerals (an age-class III-1 shad has 3 true annuli and one spawning mark and is approximately 4 years of age).

A shad that has spawned more than once is termed a "repeater." An examination of scales indicates there are few "repeaters" in the rivers investigated south of Chesapeake Bay. No repeaters were taken from the St. Johns River, Florida and repeaters made up less than 3 percent of the sample from the Neuse River, North Carolina, but were 37 percent of the sample from the Susquehannna River, Maryland. Since growth could not be calculated from scales of repeaters, because there was considerable resorption of the scale edge during the spawning run, only scales from "non-repeater" fish were used in this study and conclusions concerning growth apply only to such fish.

Methods of Investigation

Collection of material

Scales and data from 2038 adult and 164 immature shad collected during investigations on the St. Johns, Neuse, and Susquehanna Rivers, were available at the Beaufort laboratory. The St. Johns River sample was taken by gill nets and haul seines. The Neuse and Susquehanna River samples were taken by gill nets and pound nets. Immature shad were caught by a surface trawl similar to that described by Massmann, Ladd, and McCutcheon (1952). The commercial gill nets used had mesh of 5- to 6-inch stretch measure and therefore selected the larger fish although some small fish were also caught. Pound nets and haul seines, with smaller mesh, ranging from

2- to 3-inches stretch measure, were less selective. Since part of the collection from each of the rivers was taken by haul seines and pound nets, it is assumed that the composite samples for each river contain fish from all age classes present.

Fork-length measurement to the nearest tenth of an inch, weight to the nearest tenth of a pound, and sex were determined for each fish. To facilitate accurate measurement, scales were taken from the left side of the fish in an area below the insertion of the dorsal fin and at about one half the body depth. In this area on shad most scales are symmetrical.

PREPARATION AND EXAMINATION OF SCALES

Scales of shad are not imbedded tightly and are easily lost. Many of those in the samples were of the regenerate type. Such scales and those showing resorption at their edges were discarded. Plastic impressions of 2 scales used for the growth study were read twice; the first reading to determine age and the second to check age and mark the positions of the focus and annuli on strips of paper. A nomograph (Carlander and Smith, 1944) was used to determine the fork length of the fish at the time of annulus formation.

Body-Scale Relationship

The body-scale relationship was determined from a sample of 615 adult and 164 immature shad taken from the three rivers. An examination of the variation in the relationship between body length and scale radius length by sex for samples from each river revealed only small differences. Inspection of the original data, after plotting length of scale radius (y) against fork length (x), (Figure 1), showed that the body-scale relationship was such that it could be described approximately by the parabolic equation $y = ax^2 + bx + c$; which when fitted to the data on body length of scale radius, has the following value: $y = 22.58x^2 + 34.96x + 0.41$.

Age and Growth of Shad

AGE-CLASS DISTRIBUTION

Age-class distribution of 1691 shad taken in commercial catches from the St. Johns, Neuse, and Susquehanna Rivers is shown in Table 1. Differences in age-class distribution by sex in each river indicates general earlier maturity of the males. Although a few 2-year-old males have been captured in streams, presumably on their first spawning run, most of the male first-spawners were 3 years old in the St. Johns River and 4 years old in the Neuse and Susquehanna Rivers. A few females spawned first at 3 years of age, but the majority of them spawned first at 4 and 5 years of age. Shad between 6 months and 2 years of age were not available for this study because shad of these ages were at sea and not present in the rivers.

TABLE 1.—*Percentage of non-repeater shad by sex and age class from the St. Johns, Neuse, and Susquehanna Rivers.*

	St. Johns		Neuse		Susquehanna	
Age class	Male	Female	Male	Female	Male	Female
I-1					9	
II-1	61	5	16	1	5	
III-1	33	29	58	25	60	44
IV-1	6	56	26	44	21	46
V-1		10		28	5	10
VI-1				2		
Total number	193	487	400	289	92	230

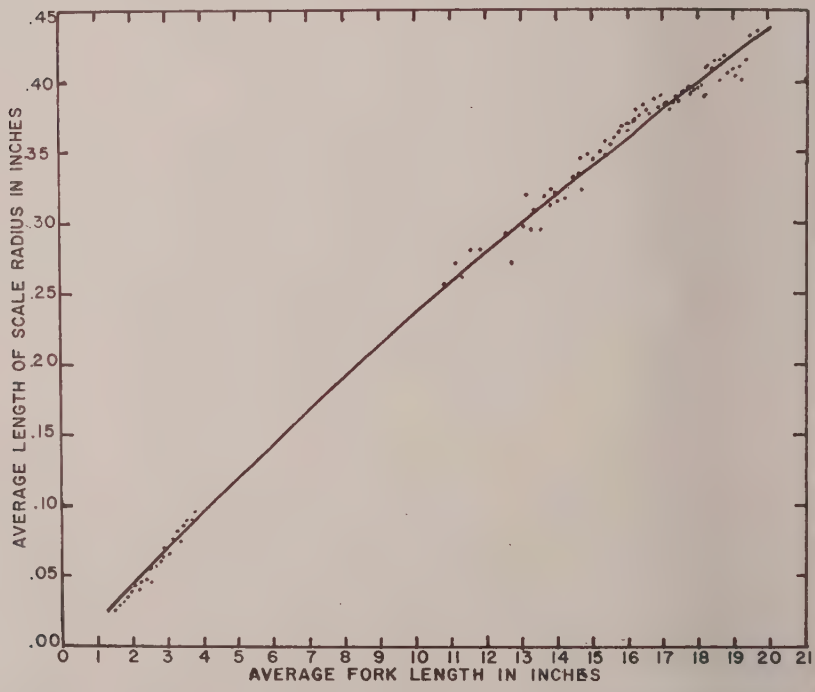

FIGURE 1.—The body-scale relationship of American shad from three southeastern rivers using curvilinear regression line.

GROWTH OF SHAD

Two shad of each sex were selected from each river by 0.1 inch size class for growth determination. Of the 1691 shad in the samples 431 were selected by this method. Female shad had a slightly faster rate of growth than males, but the difference in length between males and females of the same age class was not large. Figure 2 shows graphically differences in average growth rate and growth increment for 164 male and female shad from the Neuse River. At 4 years of age (age class III-1) females from the St. Johns River were calculated to be 0.6 of an inch longer than the males. Females from the Neuse River were 0.3 inch longer, and from the Susquehanna River 1.1 inches longer than the males (Table 2).

The relationship between fork length and total length of shad was determined so that the growth rates calculated in this study could be compared with those of other studies. Total and fork-length measurements were available[2] from 98 shad ranging in length from 15 to 22 inches. The average conversion factor for total to fork length was 0.894. This conversion factor may be subject to a small error for shad less than 15.0 inches in length.

Leim (1924, Figure 37) illustrates a scale from one of four 2-year-old shad from 6.3 to 7.8 inches fork length.[3] By using the nomograph previously mentioned, the first annulus (fresh-water mark) was calculated to have been formed when the fish was between 3.2 and 3.8 inches fork length; the second annulus between 5.4 and 6.5 inches fork length. Hammer[4] shows that the first ring (fresh-water mark) is formed when the shad leaves fresh water in the autumn of its first year. Therefore, the fresh-water mark is not a true annulus. He used 362 adult shad from the Susquehanna River to calculate the length of juveniles at the formation of the fresh-water ring. The mean of these calculated lengths was 3.6 inches.[5] This compares closely with the calculated length at the first annulus of Leim's Figure 37 (3.2 to 3.8 inches). By comparing Cating's Figure 3 (1953) with Leim's Figure 37 it can be seen that the scale in Figure 3 is similar to the area enclosed by the first ring in Figure 37. Figure 3 is of a scale from a 4- or 5-months old shad captured in fresh water. Smith (1899) says, "When 2-months-old, shad are about 2 inches long; having attained this size, they add about an inch to their length in from 2½ to 3½ months, so that when they leave the fresh water in the fall they are from 3½ to 4 inches long." The foregoing observations indicate that Leim was calling the fresh-water mark the first

[2]Unpublished data, U. S. Fishery Laboratory, Beaufort, N. C.

[3]The total length in centimeters of Leim (1924) was changed to fork length in inches by converting total length to inches and multiplying by the conversion factor 0.894.

[4]Hammer, Ralph Curtis, 1942. The homing instinct of the Chesapeake shad, *Alosa sapidissima* Wilson, as revealed by a study of their scales. Thesis, University of Maryland (typewritten).

[5]Total length in half-centimeters of Hammer (1942) was changed to fork length in inches.

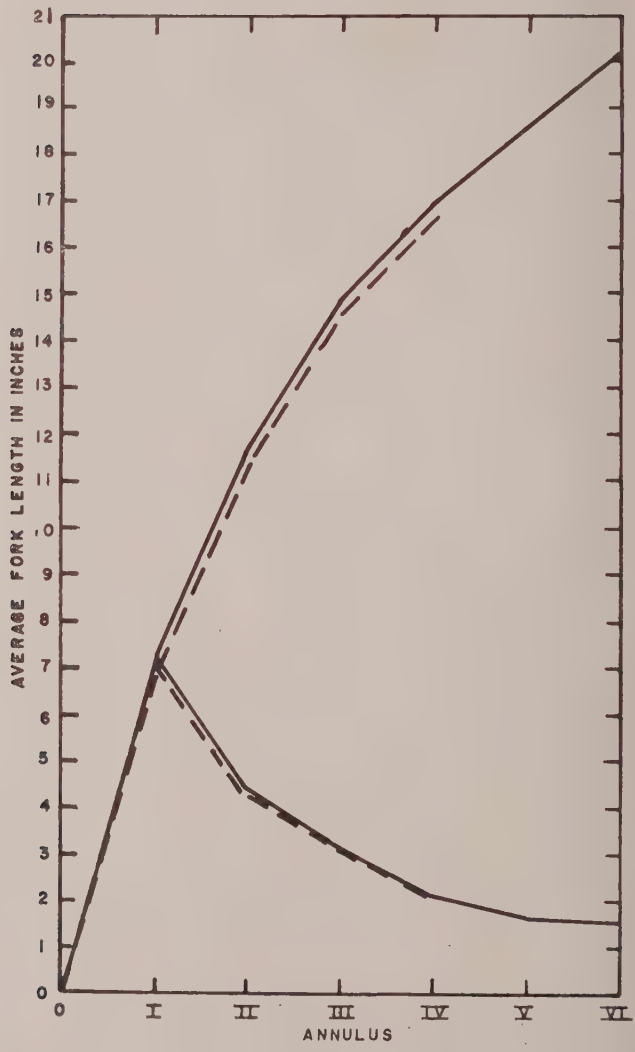

FIGURE 2.—Average calculated fork length at each annulus and average annual increment of male (broken line) and female shad (solid line) from Neuse River.

annulus, thus causing a difference of one year between his age determinations and those in this study.

Material from the St. Johns, Neuse, and Susquehanna Rivers considered in this report was compared to Leim's (1924) growth study of 5-year-old shad from Scotsman Bay, Nova Scotia, in 1920 (Table 2). The calculated lengths in his study agreed quite closely with those of the samples from the three United States rivers after correction for the one year difference in age determination.

Validity of the Annulus of Shad Scales as a Year Mark

Heretofore, no attempt has been made to validate the annulus on shad scales as the true year mark. The following three criteria of validation, similar to those suggested by Hile (1941), were applied.

1. *Modes in the length-frequency distribution of the sample should coincide with the mean calculated lengths of age groups based on scale reading.* When this method is applicable, it is usually adequate only for fish which are four years of age or younger (Rounsefell and Everhart, 1953). Two thousand thirty-eight specimens were used to find the length-frequency distributions of shad in the three rivers (Table 3). The means of the calculated fork lengths at annulus III and IV of males from the St. Johns and Neuse Rivers (Table 4) agree closely with the modes in the length-frequency

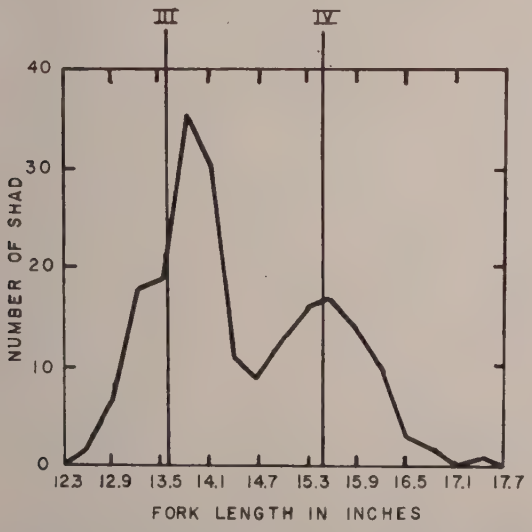

Figure 3.—Length-frequency distribution of 208 St. Johns River shad (males) compared with mean calculated lengths at annuli III and IV.

TABLE 2.—*Average calculated fork lengths in inches at each annulus for shad from samples taken from several populations along the Atlantic coast.*

River	I		II		III		IV		V		VI	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
St. Johns	6.9	7.1	10.9	11.2	13.6	13.9	15.5	16.1	—	17.6	—	—
Neuse	7.0	7.2	11.3	11.6	14.5	14.8	16.6	16.9	—	18.6	—	20.2
Susquehanna	6.5	6.9	10.5	11.2	13.0	14.2	14.8	15.9	15.9	17.5	—	—
Scotsman Bay 1920[1]	7.1	7.6	10.3	11.2	12.9	13.9	15.3	16.4	—	—	—	—

[1]After Leim (1924) with adjustment as described in text.

distributions (Figures 3 and 4). There were too few age-class II-1 female shad in the samples from the three rivers and in the male sample from the Susquehanna River to make modes in the length-frequency distributions (Table 3, footnotes). Also, there were no modes in the length-frequency distributions for age-class III-1 and IV-1 females from all three rivers and males from the Susquehanna River probably because of the overlap in lengths of shad in these two age classes. Therefore, this test could be used only for male shad from the St. Johns and Neuse Rivers.

TABLE 3.—*Length-frequency distribution of shad from the St. Johns, Neuse, and Susquehanna Rivers.*

Fork-length (inches)	St. Johns		Neuse		Susquehanna	
	Males	Females	Males	Females	Males	Females
10.4-10.6					1	
10.7-10.9					2	
11.0-11.2					1	
11.3-11.5					4	
11.6-11.8					1	
11.9-12.1						
12.2-12.4						
12.5-12.7	2				2[1]	
12.8-13.0	7				1	
13.1-13.3	18	1	3			
13.4-13.6	19	1	7			
13.7-13.9	36[1]	2	7			
14.0-14.2	30	3	13[1]			
14.3-14.5	11	7[1]	20		3	
14.6-14.8	9	10	15		5	
14.9-15.1	13	15	16		4	
15.2-15.4	16	20	8		7[2]	
15.5-15.7	17[2]	18	17	1	20	
15.8-16.0	14	31[2]	47	1[1]	42	
16.1-16.3	10	37	60[2]	1	31	4
16.4-16.6	3[3]	58	89	2	31[3]	5
16.7-16.9	2	82	70	5	24	12[2]
17.0-17.2		74	45	10[2]	21	28
17.3-17.5	1	67[3]	20	22	25	47
17.6-17.8		41	11	32	7	35
17.9-18.1		27	6[3]	51	3	56[3]
18.2-18.4		11	3	36[3]		32
18.5-18.7		7		45		35
18.8-19.0		7		39		18
19.1-19.3		1		32		6
19.4-19.6			1	25		9
19.7-19.9				7		2
20.0-20.2				5		3
20.3-20.5				4		1
20.6-20.8				3		1
20.9-21.1				1		
21.2-21.4						1
Totals	208	520	458	322	235	295

[1] Mean fork length at age class II-1.
[2] Mean fork length at age class III-1.
[3] Mean fork length at age class IV-1.

2. *There should be a regular increase in fish length with each succeeding annulus.* Such an increase is noted in successive age groups for both sexes in the samples from each river (Table 4).

3. *There should be a close agreement between average calculated length of a fish at any annulus and the average actual length of the fish of the*

TABLE 4.—*Average fork length at capture and average calculated fork length at each annulus of shad from St. Johns, Neuse and Susquehanna Rivers—expressed as inches.*

River and item	Number specimens	Age class	Sex	Length at capture	Annulus 1	2	3	4	5	6
St. Johns	36	II-1	M	13.7	6.9	11.0				
	14	II-1	F	14.4	6.9	11.3				
	31	III-1	M	15.5	6.9	10.8	13.6			
	33	III-1	F	15.8	7.1	11.0	13.8			
	7	IV-1	M	16.5	6.8	10.7	13.4	15.5		
	24	IV-1	F	17.3	7.1	11.2	14.1	16.1		
	18	V-1	F	18.6	7.4	11.3	14.1	16.1	17.6	
Total and grand	74	—	M	—	6.9	10.9	13.6	15.5		
average lengths	89	—	F	—	7.1	11.2	13.9	16.1	17.6	
Neuse	34	II-1	M	14.2	6.9	11.0				
	2	II-1	F	15.8	6.5	12.2				
	44	III-1	M	16.3	7.1	11.5	14.4			
	19	III-1	F	17.1	6.8	11.6	14.9			
	9	IV-1	M	18.0	7.2	11.7	14.7	16.6		
	24	IV-1	F	18.3	7.1	11.5	14.6	16.9		
	27	V-1	F	19.5	7.6	11.6	14.7	16.8	18.6	
	5	VI-1	F	20.5	7.8	11.9	15.5	17.7	18.9	20.2
Total and grand	87	—	M	—	7.0	11.3	14.5	16.6		
average lengths	77	—	F	—	7.2	11.6	14.8	16.9	18.6	20.2
Susquehanna	6	I-1	M	11.1	6.7					
	4	II-1	M	12.5	6.1	10.2				
	19	III-1	M	15.2	6.7	10.8	13.3			
	20	III-1	F	16.9	6.9	11.3	14.4			
	17	IV-1	M	16.6	6.3	10.2	12.7	14.9		
	22	IV-1	F	17.9	6.8	11.3	14.2	16.1		
	4	V-1	M	17.0	6.8	10.4	12.7	14.4	15.9	
	12	V-1	F	19.3	7.0	10.9	13.8	15.6	17.5	
Total and grand	50	—	M	—	6.5	10.5	13.0	14.8	15.9	
average lengths	54	—	F	—	6.9	11.2	14.2	15.9	17.5	

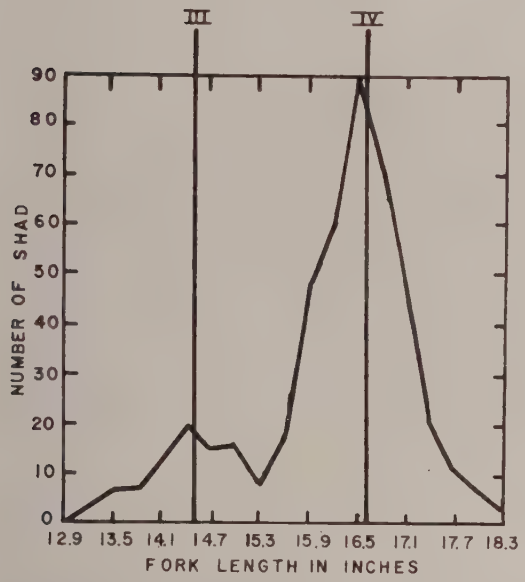

FIGURE 4.—Length-frequency distribution of 458 Neuse River shad (males) compared with mean calculated lengths at annuli III and IV.

corresponding age group at the time of capture. In all but two instances, there is fairly close agreement between actual length at capture and calculated length (Table 4). The calculated length at any annulus is closer to the actual length at capture than to any other age class. The two exceptions to this last statement are: The fork length at annulus V in Susquehanna River males and the fork length at annulus VI in Neuse River females. These samples probably were too small to calculate the average fork lengths accurately.

The first criterion was applicable to the males only from the St. Johns and Neuse Rivers. The second and third suited samples of both males and females from all three rivers. By the three preceding criteria it appears that results from aging shad from scale annuli are not in conflict with known facts about the shad and its life history.

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Literature Cited

Barney, R. L.
1925. A confirmation of Borodin's scale method of age determination of Connecticut River shad. A report of investigations concerning shad in the rivers of Connecticut, by P. H. Mitchell and Staff. Conn. St. Bd. of Fish and Game, Part III, pp. 52-60.

Borodin, N. A.
1925. Age of shad (*Alosa sapidissima* Wilson) as determined by the scales. A report of investigations concerning shad in the rivers of Connecticut, by P. H. Mitchell and Staff. Conn. St. Bd. of Fish and Game, Part II, pp. 46-51.

Carlander, Kenneth D., and Lloyd L. Smith, Jr.
1944. Some uses of nomographs in fish growth studies. Copeia, 1944, No. 3, pp. 157-162.

Cating, James P.
1953. Determining age of Atlantic shad from their scales. U. S. Fish and Wildlife Serv., Fish. Bull., 85, Vol. 54, pp. 187-199.

Greely, John R.
1937. Biological survey of the lower Hudson watershed. II. Fishes of the area with annotated list. N. Y. Cons. Dept. Biol. survey (1936), No. XI, pp. 45-103.

Hile, Ralph
1941. Age and growth of rock bass, *Ambloplites rupestris* (Rafinesque), in Nebish Lake, Wisconsin. Trans. Wisc. Acad. Sci., Arts and Lett., Vol. 48, pp. 189-337.

Leim, A. H.
1924. The life history of the shad, *Alosa sapidissima* (Wilson) with special reference to the factors limiting its abundance. Contrib. Cana. Biol., N. S., Vol. 2, No. 11, pp. 161-284.

Massmann, W. H., E. C. Ladd, and H. N. McCutcheon
1952. A surface trawl for sampling young fishes in tidal rivers. Trans. 17th N. Amer. Wildl. Conf., 1952, pp. 386-392.

Rounsefell, G. A., and W. H. Everhart
1953. Fishery Science its method and applications. John Wiley and Sons, xii + 444 pp.

Smith, H. M.
1899. Studies of young shad in the Potomac River. Rept. U. S. Fish Comm., 1898, Vol. 24, pp. cxxxviii-cxxxix.

Literature Cited

Barney, R. L.
1925. A confirmation of Borodin's scale method of age determination of Connecticut River shad. A report of investigations concerning shad in the rivers of Connecticut, by P. H. Mitchell and Staff. Conn. St. Bd. of Fish and Game, Part III, pp. 52-60.

Borodin, N. A.
1925. Age of shad (*Alosa sapidissima* Wilson) as determined by the scales. A report of investigations concerning shad in the rivers of Connecticut, by P. H. Mitchell and Staff. Conn. St. Bd. of Fish and Game, Part II, pp. 46-51.

Carlander, Kenneth D., and Lloyd L. Smith, Jr.
1944. Some uses of nomographs in fish growth studies. Copeia, 1944, No. 3, pp. 157-162.

Cating, James P.
1953. Determining age of Atlantic shad from their scales. U. S. Fish and Wildlife Serv., Fish. Bull., 85, Vol. 54, pp. 187-199.

Greely, John R.
1937. Biological survey of the lower Hudson watershed. II. Fishes of the area with annotated list. N. Y. Cons. Dept. Biol. survey (1936), No. XI, pp. 45-103.

Hile, Ralph
1941. Age and growth of rock bass, *Ambloplites rupestris* (Rafinesque), in Nebish Lake, Wisconsin. Trans. Wisc. Acad. Sci., Arts and Lett., Vol. 48, pp. 189-337.

Leim, A. H.
1924. The life history of the shad, *Alosa sapidissima* (Wilson) with special reference to the factors limiting its abundance. Contrib. Cana. Biol., N. S., Vol. 2, No. 11, pp. 161-284.

Massmann, W. H., E. C. Ladd, and H. N. McCutcheon
1952. A surface trawl for sampling young fishes in tidal rivers. Trans. 17th N. Amer. Wildl. Conf., 1952, pp. 386-392.

Rounsefell, G. A., and W. H. Everhart
1953. Fishery Science its method and applications. John Wiley and Sons, xii + 444 pp.

Smith, H. M.
1899. Studies of young shad in the Potomac River. Rept. U. S. Fish Comm., 1898, Vol. 24, pp. cxxxviii-cxxxix.

A Decimal Classification For Fisheries

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SPECIAL LIBRARIES
MARCH 1958

A Decimal Classification For Fisheries

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THE LIBRARY OF CONGRESS classification for the marine sciences was originally outlined some 50 years ago. Since this classification was first formulated, the marine sciences have taken a tremendous step forward, due in part to the impetus given to research by World War II. An even stronger driving force has been the problem of feeding the ever-increasing populations of the earth. People are awakening to the fact that there is a practically unknown world lying along the shores of many countries.

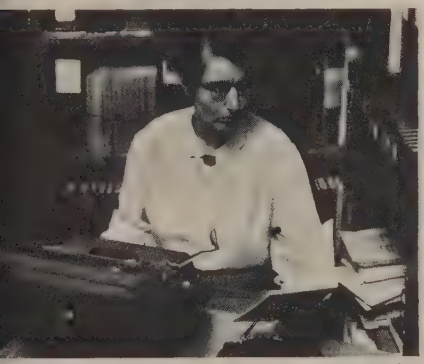
Every deep-sea expedition, the work for the International Geophysical Year, each cruise made by a fisheries research vessel—all add to our knowledge of the sea and its inhabitants. Fisheries librarians must have a classification scheme that can easily cope with the ever-expanding knowledge of the sea and the increasing number of disciplines involved in the study of the sea. The Food and Agriculture Organization classification is one answer to this troubling problem.

The Food and Agriculture Organization of the United Nations, according to Article I.1 of its charter, "shall collect, analyze, interpret, and disseminate information relating to . . . food and agriculture . . . fisheries (and) marine products." In its task of scrutinizing literature, gathering, sorting, and eventually retrieving information, the Fisheries Division, FAO, had three major problems to consider: 1) terminology and definitions; 2) classification, codification and documentation techniques; and 3) bibliographic services. This paper will be confined to classification.

FAO considered many schemes, in cluding the Universal Decimal Class fication, and found them deficient fo its purposes. It then considered anothe special classification used in forestry which had been prepared by the Inte national Union of Forest Research Or ganizations, FAO, and other bodies, an an attempt was made to devise a pa allel classification for the marine sc ences. This classification and corollar problems were discussed at a Decembe 1954 meeting in Paris, called by FAO The United States Government wa represented by Dr. George Myers o the Fish and Wildlife Service. The co sensus of the meeting was that it woul be desirable to continue with the prep aration of a classification which woul follow the pattern of the Oxford Class fication for Forestry (Doc. FAO/54 12/7289).

Following the Paris meeting, a fourt revision of this scheme (Doc. FAO 56/2/915) was prepared and was pr sented and discussed at a consultant meeting on "Documentation and Re lated Services for Fisheries Biology (Report of FAO meeting of consultant to consider documentation and relate services for fish biology, Biarritz, Franc February 25-29, 1956). Representative of FAO, International Commission fo the Northwest Atlantic Fisherie (ICNAF), International Council fo the Exploration of the Sea (ICES) an the General Fisheries Council for th Mediterranean (GFCM), were presen at this meeting in which the Unite States Government was represented b Dr. Lionel A. Walford, Dr. Herbert W Graham and Mr. Clyde C. Taylor o

e Fish and Wildlife Service. Many ggestions were made toward the im- ovement and clarification of the clas- ication as presented by FAO.



Bob Brigham

The author, Elizabeth B. Leonard, at work in the Woods Hole Laboratory Library.

As space does not permit a complete anscript of this revised scheme, the ain subject headings are listed with- t any breakdown, and then the sub- ctions, which are intended for the assification of books, are discussed:

Living aquatic resources, fisheries and aquatic problems generally. (This number would be used, in general, for such subjects as fisheries terminology, fisheries encyclopedias and general reference material.)

Physical environment. Biology.

Fishable stocks. Identification, survey, populations, dynamics of exploited populations.

Effects of natural environmental changes. Damage to and protection of the resource.

Harvesting of aquatic products. Fishing technology. Handling and transport.

Aquiculture.

Stock management. Economics of primary operations. Administering and organizing fishing enterprises.

Marketing. Storage, transport and processing of aquatic products.

8. Aquatic products and their utilization.
9. Fisheries policy. Regional, national and international studies. Socio-economics of fisheries.

The sections intended for book classification come under Section 1—Biology and include Subsections 12 to 18. A brief outline of these subsections is:

12. General Biology.
- **120.** Biological techniques.
  - **.2** Biometry.
  - **.4** Microscopy.
- **121.** Collateral biological sciences.
- **122.** Taxonomy. Evolution. Heredity and genetics.
- **123.** Embryology and development.
- **124.** Morphology.
- **125.** Histology and cytology.
- **126.** Biochemistry. Biophysics.
- **127.** Physiology.
- **128.** Microbiology. Bacteriology. Parasitology.

13. General Zoology.
- **130.2** Chemical composition.
- **131.** Physiology (Subdivided as UDC 591.1, except .5 and .9).
- **132.** Pathology.
- **133.** Embryology.
- **134.** Anatomy.
- **135.** Phylogeny. Evolution. Heredity. Genetics. Variation.
- **136.** Economic zoology.
- **137.** Histology.

14. Systematic Zoology.
(Subdivided by taxonomic codes)
- **140.** General. All divisions.
- **140.1** Scientific and common names.
- **141.** Fishes.
- **142.** Crustaceans.
- **143.** Molluscs.
- **144.** Mammals.
- **145.** Other chordates.
- **146.** Other invertebrates.
- **148.** Systematic works dealing with 2 or more of above divisions.
- **149.** Miscellaneous.

16. General Botany.

17. Systematic Botany.

18. Ecology.

Supplementary to this classification is a taxonomic classification (M.D.P. App. V(i) 16 February 1956) which is to be used with Subsection 14—Systematic Zoology. The taxonomic code for fishes (Subsection 141) is based on *Classification of Fishes Both Recent and Fossil*, by L. S. Berg, (Ann Arbor, 1947, English and Russian). There are also taxonomic codes for the other subdivisions of Subsection 14.

In addition to the taxonomic codes, there is a geographical breakdown, not only by individual countries but by regions as well. The regional breakdown is quite important, as much of fisheries research is done on that basis. The Library of Congress system does not supply such a breakdown, and I have had to work one out for areas covered by international organizations such as ICNAF, ICES and the Inter American Tropical Tuna Commission to name a few. The fishery biologist i not interested in international conven tions *per se*.

When evaluating this classificatio scheme, it is important to remembe that it was, in the main, worked out b fisheries biologists for fisheries biolo gists, and from that point of view i both a logical and an exhaustive sys tem. As fishery biology libraries are, a a rule, oriented toward the biologist, i is reasonable to use a classification tha is also oriented in that direction and i capable of infinite expansion. FAO i using this classification in its library i Rome and it is encouraging librarie limited to the marine sciences to use i for their collections.

ENVIRONMENT AND LARVAL BEHAVIOR OF SEVERAL PELECYPODS

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The article reviews the results of recent observations and experiments, conducted at the U.S. Fish and Wildlife Service Marine Biological Laboratory at Milford, Connecticut, on the behavior of larvae of several species of bivalve mollusks, chiefly the American oyster, *Crassostrea virginica*, and the hard shell clam, *Venus mercenaria*. Reference to approximately 20 other species of larvae grown at the laboratory is frequently made.

The studies were made possible because of the recent developments and improvements in the methods for obtaining ripe gametes of mollusks throughout the year and for rearing the larvae, developing from such gametes, through metamorphosis under laboratory conditions. The factors considered in this discussion are temperature, salinity, qualitative and quantitative food requirements, effects of various dissolved substances, larval diseases and others. The work was done jointly with my associates, H. C. Davis and P. E. Chanley.

The most extensive observations on effect of temperature on development and growth of eggs and larvae were made on *V. mercenaria*. They were designed to determine the entire range within which development was possible, and the optimum range. The range within which eggs could develop into shelled larvae extended from 18·0 to 31·0° C. ± 1·0° C. However, shelled larvae in early straight-hinge stage survived and grew when kept at a temperature as low as 15·0° C. or as high as 33·0° C. ± 1·0° C. The most rapid growth occurred at 30·0° C. These experiments indicated that in the early stages of development clam eggs require a narrower temperature range than is suitable for the existence of shelled larvae. No correlation was found between the temperature at which the larvae were reared and their size at setting.

Sharp changes in temperature, such as a decrease from 25·0 to 10·0° C. within a few minutes, do not kill or seriously injure larvae. These organisms may be kept for several days at low temperature, which virtually arrests the growth, and then returned to more favorable temperature where they will resume development.

The optimum salinity for development of eggs of *V. mercenaria* was approximately 26·5 parts per thousand. The upper limit was 35·0 p.p.t. but at this salinity less than 1·0% of the eggs developed. The lower limit was approximately 20·0 p.p.t., although at 22·5 p.p.t. about 80·0% of the eggs developed into normal straight-hinge larvae. A salinity of about

26·5 p.p.t. or somewhat higher was also optimum for growth of straight-hinge clam larvae, although some larvae rached metamorphosis at 17·5 p.p.t.

The optimum salinity for growth of straight-hinge larvae reared from the eggs of Long Island Sound oysters was approximately 17·5 p.p.t. Good growth was also recorded at a salinity of 15·0 p.p.t., but as soon as the salinity was reduced to 12·5 p.p.t., the rate of growth considerably decreased, although larvae grown under these conditions reached metamorphosis. However, at 10·0 p.p.t. the larvae grew even more slowly, showed very high mortality and it appeared doubtful whether they could reach setting stage. Experiments demonstrated that the older the larvae, the better they withstood a salinity of 10·0 p.p.t.

Larvae of different species display different food requirements. The species can be divided into two groups. The first, represented by *V. mercenaria* and the common mussel, *Mytilus edulis*, is able to exist and grow on many forms. The second group, represented by larvae of the American oyster, *C. virginica*, is, on the other hand, able to utilize only a few of the many micro-organisms available in the surrounding water. Organic detritus is not utilized by clam or oyster larvae and many marine bacteria supplied as food to oyster larvae cannot be utilized. Sometimes, as in the case of *C. virginica*, larvae cannot utilize the cells of green algae such as *Chlorella*, while young, but when older they are able to do so.

Representatives of 10 different genera of micro-organisms were tested to determine their relative value as food for larvae of clams and oysters. *Isochrysis galbana* and *Monochrysis lutheri* were usually the best foods for oyster larvae. These two forms, together with *Chlorococcum* sp., were the best of the foods tried for clam larvae. It is probably significant that in our experiments the four micro-organisms, *Isochrysis galbana*, *Monochrysis lutheri*, *Dunaliella euchlora* and *Dunaliella* sp., which were the best foods for oyster larvae, are all naked flagellates. Apparently, oyster larvae cannot readily utilize forms having cell walls, particularly during the early larval stages, although older larvae can utilize some forms having cell walls, such as *Platymonas* sp., *Chlorococcum* sp., *Phaeodactylum tricornutum* and *Chlorella* sp.

Clam larvae, unlike oyster larvae, can utilize forms having cell walls from the earliest larval stages. Furthermore, *Chlorococcum* sp. is perhaps the best of the foods tested for clam larvae. In addition to the presence or, perhaps, thickness of its cell wall, the toxicity of the metabolites produced by a micro-organism is an important factor in determining its food value to bivalve larvae. Thus, *Prymnesium parvum*, a naked flagellate closely related to *Isochrysis galbana*, and hence probably easily digested, is of no value as a food for bivalve larvae because of the toxicity of its metabolites.

Survival and rate of growth of larvae depended, to a large extent, upon the number of food cells present in the sea water. Sometimes the

optimum concentrations of these cells depended upon their size. The larvae may be quickly killed if the food cells are too numerous. Death may be caused either by the cells themselves, by substances liberated by these cells or by a combination of the two, because dense concentrations of phytoplankton, such as *Chlorella*, affect the larvae both mechanically, by interfering with the swimming and feeding organs, and chemically, by secreting external metabolites. Some forms of phytoplankton were found to be extremely toxic, killing the larvae even when these food cells were present in comparatively small concentrations. Rich bacterial flora in larval cultures can also cause heavy or complete mortality of the larvae.

In certain respects larvae are hardy organisms and are able to survive vigorous agitation of the water in which they live. This was noticed in strongly agitated laboratory cultures and supported by observations in Long Island Sound where even after strong hurricanes the larvae of many bibalves were found in considerable numbers, and oyster larvae were setting even during the hurricanes.

Considerable evidence has been accumulated to show the presence or absence in the water of some unknown substances which may affect the ability of larvae to utilize the available food. These substances are still unknown but they may be toxic external metabolites, hormones or toxins produced by bacteria.

Several larval diseases and parasites have been observed under laboratory conditions. Of these the fungus of the genus *Stirolpidium* appeared to be the most common and destructive to larvae of *V. mercenaria* and several other species. On the other hand, larvae of the American or Japanese oyster, *C. virginica* or *C. gigas*, respectively, appeared to be not easily susceptible to this disease. Another fungus, *Labyrinthula* sp., was recently noticed in diseased clams and several epidemics apparently caused by bacteria were also observed.

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SOME ASPECTS OF BEHAVIOR OF OYSTERS AT DIFFERENT TEMPERATURES

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The oyster, *Crassostrea virginica* Gmelin, is a sedentary mollusk which must pump definite quantities of water through its gills, to obtain the food and oxygen necessary for its existence, and to get rid of the waste products. The stream of water created by a pumping oyster can easily be seen if the latter is kept in a shallow tray in water just deep enough to cover it. Even casual observations will show that the quantity of water pumped by an oyster changes from time to time, and that different oysters may pump at different rates.

In keeping oysters under laboratory conditions it is, obviously, of advantage to know the approximate quantity of water needed for their normal existence. The same information is of practical use to oyster cultivators in deciding the number of oysters that can be planted in a certain area to achieve the best growth. Furthermore, because of the recent progress in the artificial propagation of bivalves (Loosanoff and Davis, 1950; Loosanoff, 1954), which is now leading to mass production of clams and oysters under hatchery conditions, and because of the recent interest in the utilization for shellfish culture of small, salt water ponds, where annual fluctuations in temperatures may be great, extending in some regions from nearly 0.0° to 32.0° C. or even higher, a more complete knowledge of the behavior of the mollusks within this temperature range is needed. Finally, the differences in the rates of water pumping at the same temperatures by oysters from different geographic areas may be used as the criterion to ascertain the existence of different physiological races.

Studies of various aspects of filtration of the filter-feeding invertebrates, including oysters and closely related mollusks, have been made by many investigators. Comprehensive reviews of several hundred articles on these subjects were recently offered by Verwey (1952) and Jørgensen (1955); therefore, only those dealing directly with rates of water pumping by bivalves, especially oysters, will be referred to here.

The first comprehensive studies of the rate of pumping of the American oyster, *C. virginica,* at different temperatures were made by Galtsoff (1928a, 1928b). He used two methods. The first, the so-called "tank method," was designed primarily to collect the water after it had passed through the gills. The second or "carmine method" was devised to measure the rate of movement of the column of water flowing from the exhalant chamber through a glass tube. Galtsoff concluded that the maximum flow of water produced by an adult oyster, three to four inches in length, was 3.9 liters per hour at a temperature of 25.0° C. Galtsoff's conclusions were challenged by Nelson (1935, 1938) who considered these figures too low and thought that the methods used by Galtsoff unfavorably affected the experimental

animals. Nelson, therefore, believed that Galtsoff's data did not truly present the normal activities of oysters. Nelson (1935) also reported that, instead of the 3.9 liters per hour indicated by Galtsoff as the maximum quantity of water that can be pumped by an oyster, some of the animals in his experiments pumped water at the rate of approximately 26.0 liters per hour. In our own work, we have recorded pumping rates of individual oysters as high as 34.0 liters per hour, *i.e.*, about ten times greater than Galtsoff's maximum (Loosanoff and Nomejko, 1946).

Most of Nelson's observations, as well as ours and those of several other investigators, were made, however, while studying various aspects of the physiological behavior of oysters and not during the studies devoted primarily to the evaluation of the effects of temperature upon their pumping rate. Since the need of more complete information on this subject still existed, the experiments discussed in this paper were conducted.

I wish to express my appreciation to Charles A. Nomejko for tabulating some of the data and for preparing photographs of the kymograph records, to Barbara J. Myers for the statistical treatment of the data used in this article and to Rita S. Riccio for her help in preparing the manuscript.

Methods

Only Long Island Sound oysters were used in these studies. For the sake of uniformity, they were selected to approximate the following standards: length—between 100.0 and 110.0 mm.; width—between 80.0 and 85.0 mm.; depth—between 30.0 and 35.0 mm.; and volume—between 85.0 and 100.0 cc. Before the oysters were used they were conditioned for several days at the temperature to be employed in the experiment.

The method for measuring the rate of flow of water through the gills of the oysters was based on the suggestions and apparatus of Moore (1910), Galtsoff (1926) and Nelson (1936), and was fully described in our article on feeding of oysters in relation to different concentrations of micro-organisms (Loosanoff and Engle, 1947). Here it is sufficient to mention that the so-called "rubber apron" method interfered in no way with the normal activities of the oysters and allowed us to collect and measure accurately the quantities of water pumped by them. Both the rate of pumping and the shell movements of the experimental oysters were continuously recorded by kymographs.

The temperature range covered by these experiments extended from about 0.0° to 38.0° C. The temperatures were usually maintained within $\pm$ 0.5° C., and the temperature intervals were 2.0° C. apart. The salinity of the water was usually about 27.0 p.p.t. and the pH, about 7.7.

In all these experiments the oysters were kept in running water, a condition which assured a more normal behavior than if the oysters had been confined to a small container repumping, time after time, the same water which, eventually, could become heavily laden with excretory products. The periods of observation extended from five to seven hours. Therefore, the conclusions offered here refer to these comparatively short periods, and the rates of pumping, as found in these experiments, would not necessarily be representative of longer exposures.

Results

Our studies, an abstract of which has already been offered (Loosanoff, 1950), consisted of 478 individual observations. However, because many oysters either did not open at all or opened but did not pump water, the conclusions are based, actually, on 337 experimental records (Table I).

The lack of activity, as could be expected, was virtually confined to the lower temperatures. Below 2.0° C. only one of eight oysters pumped. It opened its shells when the temperature was only 1.2° C. and, regardless of the somewhat ir-

Table I

Average rates of water pumping, in cc. per hour, of groups of oysters subjected for approximately six-hour periods to temperatures ranging from 0.0° to 38.0° C.

Temperature intervals °C.	Number of oysters			Pumping rate	
	Total	Open	Pumping	Average	Maximum
0.0– 2.0	8	2	1	113	—
2.1– 4.0	52	22	1	863	1,020
4.1– 6.0	28	14	5	180	266
6.1– 8.0	20	12	6	495	1,197
8.1–10.0	36	21	16	763	1,594
10.1–12.0	36	24	22	2,914	4,303
12.1–14.0	32	25	22	3,902	5,409
14.1–16.0	28	27	26	4,344	5,787
16.1–18.0	21	21	21	9,083	11,583
18.1–20.0	33	33	33	7,020	9,773
20.1–22.0	42	42	42	9,802	13,341
22.1–24.0	24	24	24	7,795	10,802
24.1–26.0	14	14	14	9,537	12,635
26.1–28.0	20	20	20	9,366	11,569
28.1–30.0	24	24	24	12,983	15,155
30.1–32.0	19	19	19	11,813	16,253
32.1–34.0	20	20	20	8,948	12,856
34.1–36.0	17	17	17	2,785	4,201
36.1–38.0	4	4	4	2,449	3,884
Total	478	385	337	—	—

regular and feeble shell movements, it produced a weak but, nevertheless, real flow of water. The ability to pump water at low temperature was also recorded for another individual that pumped a relatively large quantity of water at a temperature between 2.7° and 3.3° C. and maintained such a pumping rate for several hours (Fig. 1). Hopkins (1933) working on the closely related species, *Crassostrea gigas,* also reports that the distinct flow produced by this mollusk was observed and recorded at as low a temperature as 2.6° C.

Since some of the oysters exposed to very low temperatures not only kept their shells open, but also pumped small quantities of water, experiments were devised to ascertain whether these oysters were ingesting food under such conditions. They were conducted during February when the temperature of Milford Harbor water is at its lowest. Three-year-old oysters, brought from outdoors, were placed into in-

dividual glass dishes which, in turn, were placed in shallow, white enamel trays of cold, running sea water. A cold culture of deep-green *Chlorella* was added as a biological indicator, to appear in the feces if the oysters fed.

Of the 90 oysters kept for 24 hours at a temperature ranging between 2.0° and 3.0° C., only one individual passed a small quantity of true feces. However, about 15 per cent of the oysters formed pseudo feces. When the temperature was kept between 3.0° and 4.0° C., approximately one-half of the 90 oysters formed pseudo feces, but only a single case of true feces was observed. Thirty oysters from this group were opened and examination showed that in all but one case their stomachs were empty and crystalline styles absent. The same results were obtained when the temperature ranged between 4.0° and 5.0° C. However, when the temperature was kept between 5.0° and 6.0° C., 11 of the 90 oysters expelled true feces, two of them in large quantities, and over 75 per cent formed pseudo feces.

These experiments have shown that, although feeding of oysters below 5.0° C. occurs only as an exception, a relatively high percentage may form pseudo feces,

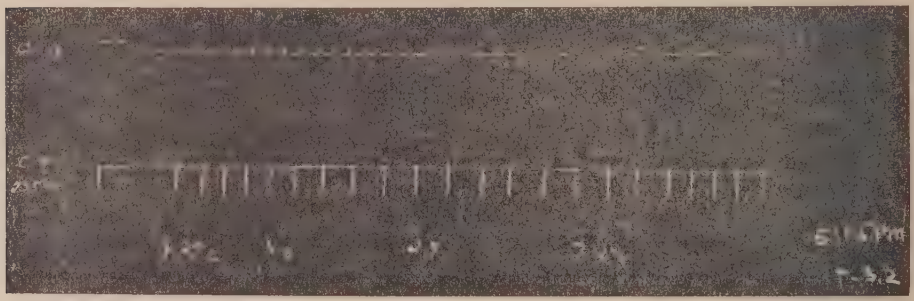

FIGURE 1. Kymograph record of shell movements (1st line) and rate of pumping (2nd line) of an oyster exposed to water temperature ranging between 2.7° and 4.2° C. from 11:45 A.M. to 6:15 P.M. Each vertical mark of the second line designates the discharge of 235 cc. of water pumped by the oyster.

even at a temperature as low as 2.0° or 3.0° C. The explanation as to why pseudo feces can be produced at lower temperatures than true feces lies, perhaps, in the observation made by Galtsoff (1928a), that the frontal cilia are able to transport the particles along the surface of the gills at a temperature of only about 3.0° C., while the lateral cilia can, as a rule, produce a current only when the temperature of the surrounding water is about 5.0° C.

The observations that some oysters feed at low temperatures are supported by those made by Nomejko and Chanley of Milford Laboratory who, in conducting a survey in Long Island Sound on March 11, 1954, dredged an oyster which possessed a well-developed crystalline style and contained food in its stomach. The temperature of the water at that time was approximately 3.0° C.

Our studies also showed that many oysters which open at the lower temperature may move their shells steadily, but pump no water. Twenty-one of the 22 oysters which opened at temperatures between 2.1° C. and 4.0° C. behaved in this manner (Table I).

Our observations lead us to believe that Galtsoff's (1928a) statement, that in

C. virginica no current is produced and no feeding occurs at or below 5.0° C., should be qualified because this rule, obviously, does not apply to all individuals. His generalizations, nevertheless, remain applicable to the large majority of the oysters.

The average and maximum rates of pumping of the groups of oysters within each temperature interval are given in Table I. In general, the rate of pumping remained low until the temperature interval of 8.0°–10.0° C. was reached. After that, and until the temperature of about 16.0° C. was attained, it showed a moderate increase. No radical fluctuations were recorded, however, between this point and

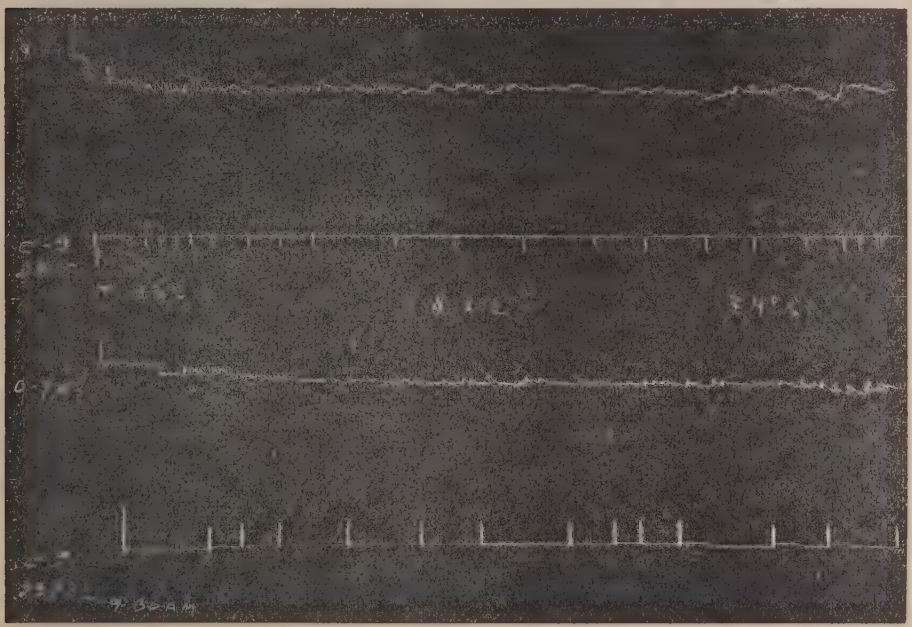

FIGURE 2. Kymograph record showing shell movements (1st and 3rd lines) and rates of pumping (2nd and 4th lines) of two oysters exposed to temperatures ranging from 8.3° to 9.3° C. from 9:30 A.M. to 2:15 P.M. Each vertical mark on the second line designates the discharge of 280 cc. of water pumped by the oysters, while each mark of the fourth line shows the discharge of 237 cc.

the temperature of 28.0° C. The greatest average rate of pumping, 12,983 cc. per hour, was recorded between 30.0° and 32.0° C. After passing the maximum, the relatively fast pumping continued until about 34.0° C. and then abruptly decreased.

Some aspects of pumping at different temperatures are demonstrated in this article by photographs of the kymograph records showing both shell movements and rates of pumping. At comparatively low temperatures, such as 8.0° to 9.5° C., shell movements of the oysters may not be well defined and the amount of water pumped through the gills remains relatively small (Fig. 2). As the temperature of the water increases toward the optimum range, many oysters begin to display the type of shell movement called "staircase" or "treppe," which some students think

is due to chemical stimulation affecting the experimental oysters with a gradual increase in intensity. We hesitate to accept this as a satisfactory explanation of the phenomenon. In many of our experiments the "staircase" shell movement occurred in normal-feeding oysters, although, as shown in Figure 3, this type of shell movement was often observed soon after the oysters opened and began to pump.

In our studies usually two or four oysters were under simultaneous observation, receiving the same amount of water, connected to the same kymograph and treated identically in all other respects. Yet, in many instances, including the one shown in Figure 4, the "staircase" type of shell movement was displayed at any given time

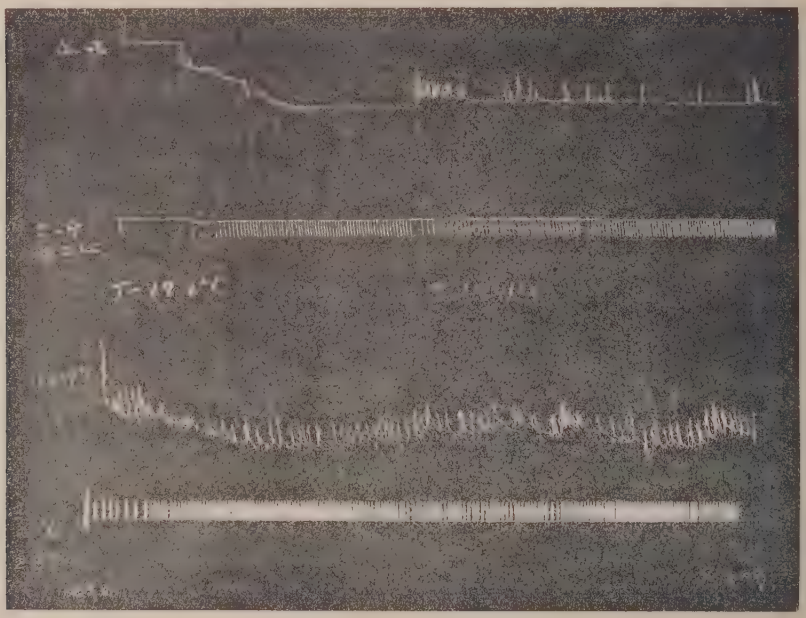

FIGURE 3. Kymograph record showing shell movements (1st and 3rd lines) and rates of pumping (2nd and 4th lines) of two oysters exposed to temperatures ranging from 17.2° to 17.4° C. from 11:05 A.M. to 4:15 P.M. Each vertical mark on the second line designates the discharge of 280 cc. of water pumped by the oysters, while each mark of the fourth line shows the discharge of 237 cc.

by one oyster only. This clearly indicated that it was not a specific chemical in the water that was responsible for stimulation of the oysters leading to this type of shell movement. Obviously, further physiological studies are needed to explain the cause of the "staircase" type of shell movement.

Within the favorable temperature range many oysters were recorded as pumping over 20,000 cc. per hour, and several individuals were observed pumping at the rate of 25,000 to 29,000 cc. per hour. The maximum rate of pumping for an individual oyster was recorded at a temperature ranging between 24.1° and 24.5° C. when one of the two oysters (indicated as O-10 in Figure 4) averaged 37,446 cc. per hour for a period of about five hours, and for several shorter periods of about 15 minutes

pumped at the rate of about 40,000 cc. per hour. Because of such a rapid rate of pumping the strokes of the needle on the kymograph drum, each representing a discharge of 237 cc. of water, were made so close to each other that the record appeared blurred. Fortunately, by employing the low power of a dissecting microscope the strokes could be accurately counted and the record properly analyzed and evaluated.

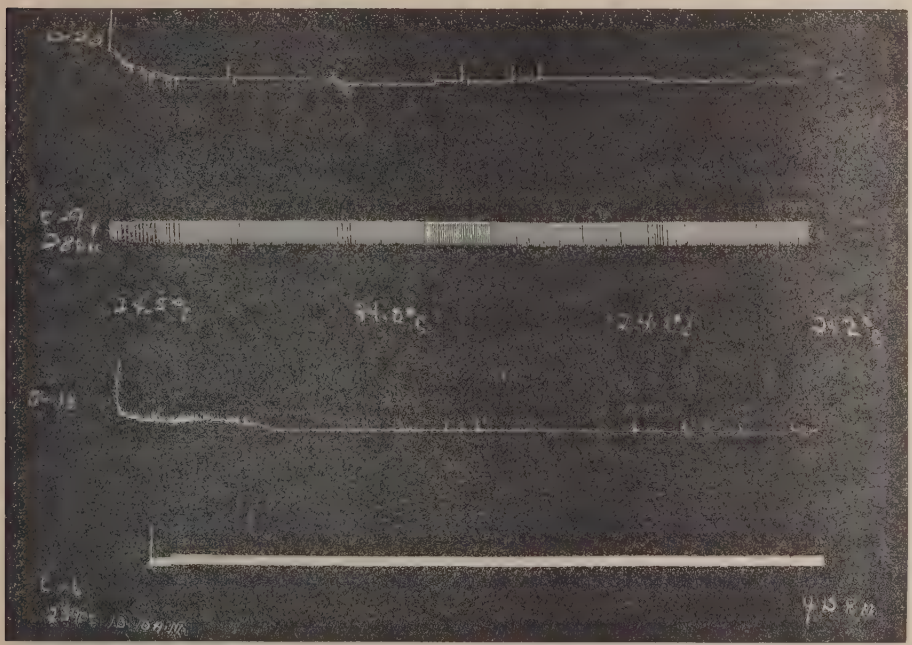

FIGURE 4. Kymograph record showing shell movements (1st and 3rd lines) and rates of pumping (2nd and 4th lines) of two oysters exposed to temperatures ranging from 24.0° to 24.5° C. from 10:10 A.M. to 4:15 P.M. Each vertical mark on the second line designates the discharge of 280 cc. of water pumped by the oysters, while each mark of the fourth line shows the discharge of 237 cc.

Incidentally, studies of many of our records indicate that often, at favorable temperatures, when the shells of the oysters are open and relatively motionless, large quantities of water are pumped. This is well demonstrated by the activities of the two oysters in Figure 4, one of which pumped the record quantities of water and the other also pumped at a rapid rate.

Almost immediately after passing the temperature level of 32.0° C. and, actually, in some instances, even between the temperatures of 31.1° and 32.0° C., certain signs began to appear, indicating that some oysters were being unfavorably affected. Among these signs were changes in the character of the shell movements, complete closing of the shells and cessation of pumping at frequent intervals, and a reduced rate of pumping even during the period when the shells remained open. Within the range of 34.1° to 36.0° C. these symptoms became more pronounced (Fig. 5).

Above 36.1° C. the type of shell movement became even more abnormal, and the oysters stayed closed approximately two-thirds of the time exposed.

To determine the significance of the differences in the average pumping rates of oysters at the different temperature intervals, a simple analysis of variance was employed. It was found unnecessary to compute all the *t*'s between adjacent temperature intervals. The same objective could be achieved by using a simple analysis of variance to test for homogeneity within each of the several apparently homogeneous levels, and also to test for the significance of the differences between these levels. These tests showed homogeneity within the following five temperature intervals: 4.1°–10.0° C., 10.1°–16.0° C., 16.1°–28.0° C., 28.1°–34.0° C., and 34.1°–38.0° C. The means for these five levels are shown in Figure 6 and are 593; 3,714; 8,727;

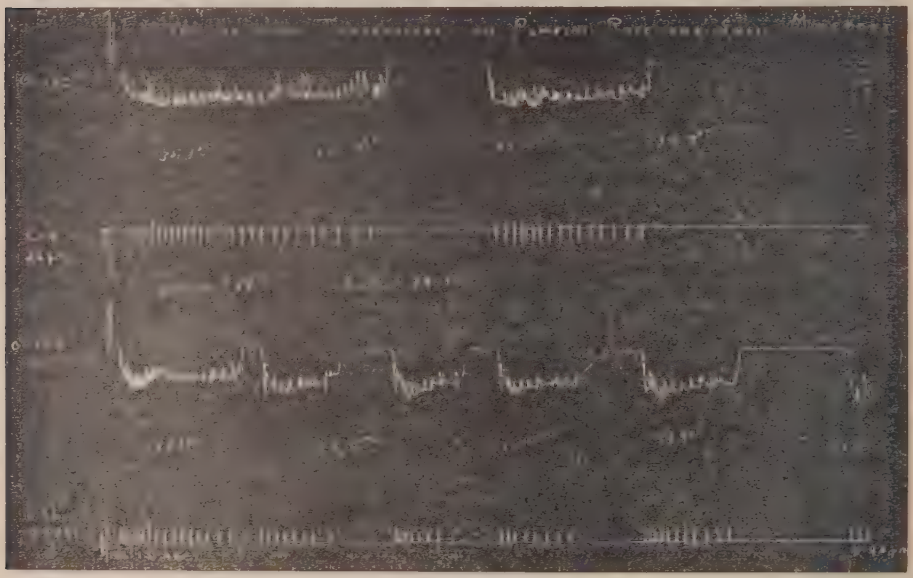

FIGURE 5. Kymograph record showing shell movements (1st and 3rd lines) and rates of pumping (2nd and 4th lines) of two oysters exposed to temperatures ranging from 34.9° to 35.2° C. from 11:15 A.M. to 6:40 P.M. Each vertical mark on the second line designates the discharge of 268 cc. of water pumped by the oysters, while each mark of the fourth line shows the discharge of 232 cc.

11,365 and 2,762 cc., respectively. The analysis indicated, as expected from inspection of this figure, that there were highly significant differences among these five levels. It was concluded, therefore, that the average pumping rate can be described as being related to these differences.

There are ecological situations in nature where changes in the temperature of the water are frequent and rapid. Many small, shallow, salt water ponds, of the type that can be adapted to shellfish cultivation, may belong to this category. Oysters living in such ponds or other similar bodies of water may experience such changes in temperature, especially during early spring and late autumn when the temperature of the water may quickly cool off during the night, decreasing to almost

0.0° C., and rapidly rise during the daytime. The question that naturally arises for such a situation is, how are the oysters affected by such changes and do they resume normal pumping regardless of the rapid change in the temperature from nearly freezing to about 15.0° C. or even higher?

The first series of experiments designed to answer the above question was conducted in October. The oysters were brought from outdoor tide-filled tanks, where the temperature of the water was about 13.0° C. One-half of the oysters, which served as the control, were placed in an aquarium in which the water temperature

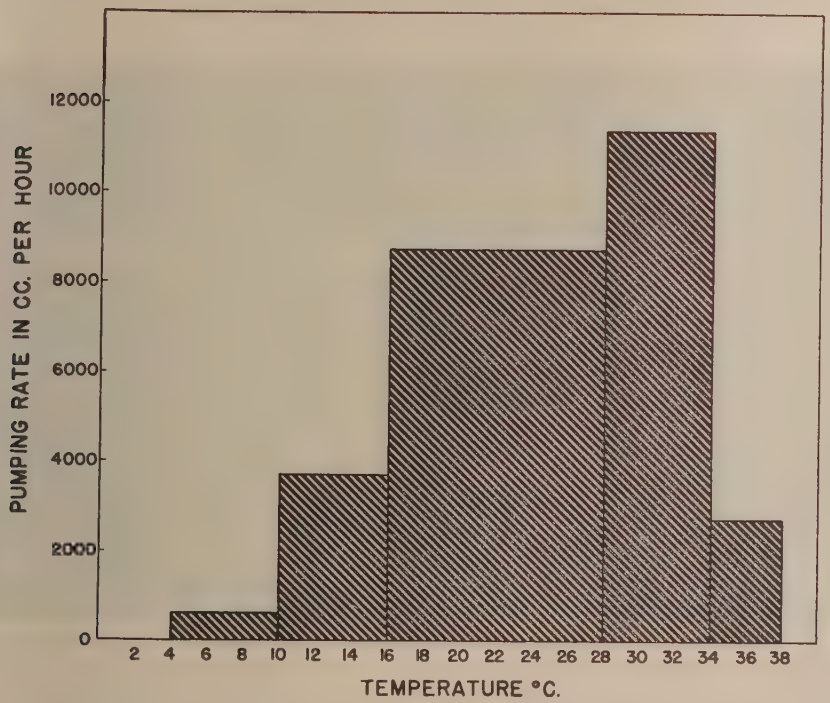

FIGURE 6. Mean rate of water pumping by oysters at five homogeneous temperature levels.

was kept at about 18.0° C. The other half were put in special containers in the refrigerator, where the temperature was about 3.0° C., and kept there from eight to 12 days. After this period at low temperature these oysters, as well as those serving as the control, were attached to kymographs. Extreme care was exercised during the handling to maintain the low temperature of the water for the refrigerated oysters. When the oysters of both groups were ready and attached to the kymographs a flow of water, about 18.0° to 20.0° C., was introduced simultaneously to all chambers, displacing the cold water surrounding the refrigerated oysters, and the behavior of all specimens was recorded from then on.

In a second series of experiments conducted in the middle of the winter (Fig. 7) the low-temperature oysters were not kept in the refrigerator but in the outdoor

tanks where the temperature of the water was near 0.0° C. The oysters which were to serve as the control were, however, kept for three weeks in the laboratory at room temperature before being used in the experiments. In all other respects the methods used in the two series were the same. Altogether, in the two series of experiments, 33 control and 31 experimental oysters were used.

Student's "*t*" test was made to determine the significance of differences in the average pumping rate of the two groups. Because the "*t*'s" were far from significant, it was concluded that sudden upward changes in temperature, such as from 1.5° C. to about 18.0° C. (Fig. 7), had no significant effect on the pumping rate of the "cold water" oysters when such rate was compared with that of the control

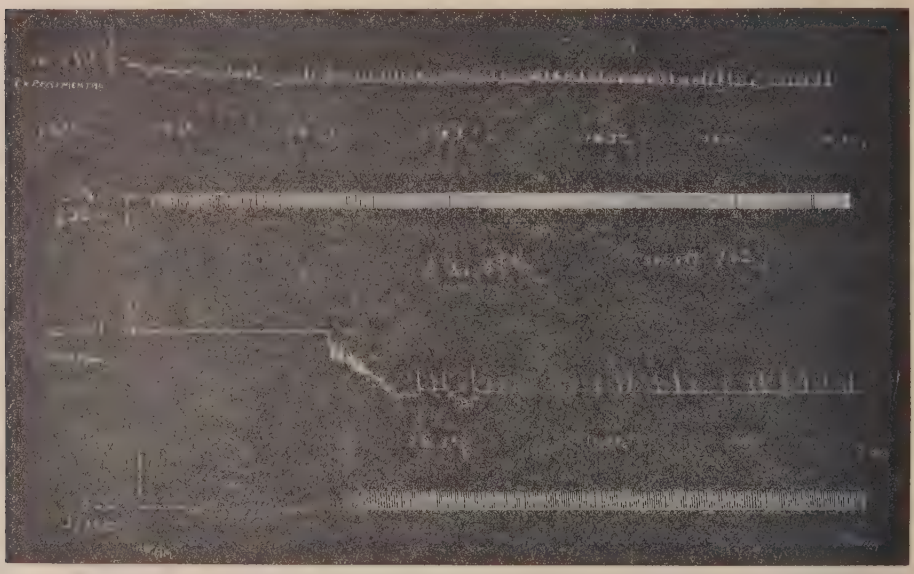

FIGURE 7. Kymograph record showing shell movements (1st and 3rd lines) and rates of pumping (2nd and 4th lines) of two oysters from 9:25 A.M. to 4:30 P.M. One, O-134, was exposed to rapid change of temperature from 1.5° to about 18.0° C., while the control oyster, O-141, was constantly subjected to the same temperature of about 18.0° C. Each vertical mark on the second line designates the discharge of 236 cc. of water pumped by the oysters, while each mark of the fourth line shows the discharge of 251 cc.

oysters. It was demonstrated, nevertheless, that there was a highly significant tendency of the oysters subjected to sudden changes from low to high temperature to open and pump almost immediately after the change was made, while the control oysters, as illustrated in Figure 7, usually required a much longer time to open their shells and begin pumping.

The results of these experiments differ from those of Galtsoff (1946) who, after keeping two oysters for 24 hours at 5.0° C. and then exposing them to a temperature of about 21.0° or 22.0° C., concluded that the shell movements of those oysters were abnormal and that they started to pump only on the third or fourth day after they had been placed in warmer water. We found no such abnormalities in the

shell movements of the individuals used in our experiments (Fig. 7). Moreover, as already mentioned, the majority of our oysters previously kept in cold water opened and began pumping almost immediately, not after three or four days as found by Galtsoff. Our observations indicated, consequently, that the response of the oysters to a sharp and quick increase in temperature, from near 0.0° to about 15.0° to 20.0° C., is rapid and results in apparently normal pumping. The oysters, therefore, are physiologically well adapted to such changes which they, no doubt, often encounter in nature, for example, when living on the tidal flats where, at the autumn low tide, the night air may cool the water of the small pools containing the oysters almost to freezing, while the incoming tide may cover the same oysters with much warmer water.

Discussion

The rate of water pumping of different bivalves has been studied by a number of investigators. Among them, Jørgensen (1949) and Willemsen (1952) studied it in the common mussel, *Mytilus edulis;* Fox *et al.* (1937) and Rao (1953) worked on the closely related species, *M. californianus;* Willemsen (1952) also determined the quantities of water pumped by cockles, *Cardium edule;* Hopkins (1933, 1935) conducted extensive studies on the pumping of the Japanese commercial oyster, *Crassostrea gigas,* while Chipman and Hopkins (1954) determined the rate of water filtration by the common scallop, *Pecten irradians.* Most of these workers, except Hopkins, used the so-called indirect method based on a reduction of the number of particles or plankton organisms in suspension in the water in which the mollusks were kept. Hopkins used his own "cone" method by means of which he could determine only the relative rate at which the oysters pumped at different temperatures.

The most extensive observations on the rate of water transport were conducted on the American oyster, *C. virginica.* Except for Galtsoff's (1928a) pioneer experiments and Jørgensen's (1952) studies, investigators have used the direct or so-called "rubber apron" method, which permits measuring the actual quantities of water passed by oysters without interfering with their normal behavior. Most of these studies, however, including those of Loosanoff and Nomejko (1946), Loosanoff and Engle (1947) and Galtsoff *et al.* (1947), were made within relatively narrow temperature ranges not including the low or high temperature zones. Results of studies by Nelson (1935) and Loosanoff (1950), covering broader ranges, were presented only as brief abstracts.

As already mentioned, Galtsoff's (1928a) early experiments were criticized because the methods that he was then employing adversely affected the oysters (Nelson, 1938). Yet, regardless of the defects in his methods, Galtsoff, although giving rather low figures for the quantities of water pumped by oysters, indicated, nevertheless, quite correctly the general trend of the changes in the rate of pumping in relation to different temperature levels. For example, he observed that no feeding took place at 5.0° C. or lower. These conclusions, with the few exceptions demonstrated by our studies and by Hopkins' (1933) observations on the closely related species, still hold true for the majority of the population of *C. virginica* of northern waters. Galtsoff's observations that between 15.0° and 25.0° C. the fluctuations in the rate of pumping of individual oysters were small, strongly support the validity of our conclusions that between 16.0° and 28.0° C. the rate of pumping showed no marked fluctuation. Finally, his figures indicate a sharp drop in the rate of pump-

ing after the temperature reaches and passes 34.0° C., as was also observed in our experiments.

Our observations showed that the highest average rate of flow of water through the gills of the oysters was achieved at about 29.0° C. (Table I). In this respect our results are in agreement with those of Nelson (1935) who determined that the maximum pumping in oysters occurs near 30.0° C. Our conclusions also resemble those of Galtsoff (1928b) that the optimum temperature for the mechanical activities of the oyster gills lies between 25.0° and 30.0° C. However, Galtsoff found that the maximum rate of pumping occurs at 25.0° C., somewhat lower than that recorded by Nelson (1935) or found in our studies. Nevertheless, considering Galtsoff's findings concerning the temperature at which the maximum activity of the oyster gills takes place, the three series of studies are in close agreement. Collier (1954) thinks, however, that even on the Gulf Coast the optimum temperature range for *C. virginica* lies between 15.0° and 25.0° C.

As to the maximum quantities of water pumped by *C. virginica,* there is considerable disagreement between the conclusions of the earlier workers, whose studies were reviewed by Galtsoff (1928a), and the more recent ones. The former estimated that oysters are capable of pumping only a few liters per hour. Wells (1926) gave the highest figure, advancing the opinion that at a favorable temperature oysters can average more than 7.5 liters per hour. His conclusions, however, were strongly challenged by Galtsoff (1928a), who expressed doubt that oysters can pump water at that rate.

Later investigators, who used the "rubber apron" method, have shown that the quantities of water pumped by oysters are much greater than those suggested by earlier workers. Nelson (1935) gives 26.0 liters per hour as the maximum quantity. Our maximum figure for a single oyster, as already mentioned, was 37,446 cc. for one complete hour, and an even higher rate was recorded for shorter periods. The maximum average hourly rate of pumping for a group of oysters was recorded within the temperature range of 28.1° to 30.0° C. and was 12,983 cc.; the maximum hourly rate, recorded between 30.1° and 32.0° C., was 16,253 cc. (Table I). Galtsoff *et al.* (1947) gave 9.6 liters as the average and 16.0 liters as the maximum hourly rate of water pumped by the oysters of York River, Va. Jørgensen's (1952) figures obtained by somewhat different methods are, nevertheless, very close to ours, being 11.0 and 15.5 liters per hour for the average and maximum rates, respectively. These figures attest the ability of the oysters to pump large quantities of water and indicate the importance of considering the water requirements of these mollusks in experimenting with them, or in their cultivation.

Summary

1. Some adult Long Island Sound oysters are able to pump water at a temperature as low as about 1.0° C. Oysters with crystalline style and food in their stomachs may occasionally be found in northern waters in winter.

2. Approximately 15 per cent of the oysters exposed to temperatures ranging from 2.0° to 3.0° C., and approximately 50 per cent of the oysters kept between 3.0° and 4.0° C. formed pseudo feces.

3. The average and maximum rates of pumping of the groups of oysters exposed to temperatures from 0.0° to 38.0° C. were determined. The rate remained low

under 8.0° C. Within the range from 8.1° to 16.0° C. the rate steadily increased. Between that point and about 28.0° C. the rate showed no marked fluctuation. A further increase was noted between 28.1° and 32.0° C. It is within this range that the maximum average rate of pumping of 12,983 cc. per hour was recorded. Between 32.1° and 34.0° C. the rate was also rapid. Beyond 34.1° C. the oysters showed a marked decrease in the rate of pumping and their shell movements were abnormal.

4. The maximum rate of pumping for an individual oyster averaging 37,446 cc. per hour was recorded at the temperature of about 24.0° C. For short periods of five to 15 minutes the rate of pumping of the same oyster exceeded 40,000 cc. per hour.

5. Statistical tests showed homogeneity of the rates of pumping within the following five temperature intervals: 4.1°–10.0° C., 10.1°–16.0° C., 16.1°–28.0° C., 28.1°–34.0° C. and 34.1°–38.0° C. The means for these five intervals were 593; 3,714; 8,727; 11,365 and 2,762 cc. per hour, respectively. Highly significant differences among these five levels were indicated by statistical analysis.

6. The rate of pumping of oysters kept at a temperature below 5.0° C. and then quickly changed to the higher temperature of 18.0° to 20.0° C. was virtually the same as the control oysters, thus indicating that the response of the oysters to such changes in environment and their adjustment to these changes are rapid.

LITERATURE CITED

Chipman, W. A., and J. G. Hopkins, 1954. Water filtration by the bay scallop, *Pecten irradians*, as observed with the use of radioactive plankton. *Biol. Bull.*, **107**: 80–91.

Collier, A., 1954. A study of the response of oysters to temperature, and some long range ecological interpretations. *Nat. Shellfish. Assoc. Conv. Address*, 1953: 13–38.

Fox, D. L., H. N. Sverdrup and J. P. Cunningham, 1937. The rate of water propulsion by the California mussel. *Biol. Bull.*, **72**: 417–438.

Galtsoff, P. S., 1926. New methods to measure the rate of flow produced by the gills of oyster and other molluscs. *Science*, **63**: 233–234.

Galtsoff, P. S., 1928a. Experimental study of the function of the oyster gills and its bearing on the problems of oyster culture and sanitary control of the oyster industry. *Bull. Bur. Fish.*, **44**: 1–39.

Galtsoff, P. S., 1928b. The effect of temperature on the mechanical activity of the gills of the oyster (*Ostrea virginica* Gm.). *J. Gen. Physiol.*, **11**: 415–431.

Galtsoff, P. S., 1946. Reaction of oysters to chlorination. *U. S. Fish and Wildlife Service, Research Report*, **11**: 1–28.

Galtsoff, P. S., W. A. Chipman, Jr., J. B. Engle and H. N. Calderwood, 1947. Ecological and physiological studies of the effect of sulphate pulp mill wastes on oysters in the York River, Virginia. *Fish. Bull. 43, U. S. Fish and Wildlife Serv.*, **51**: 57–186.

Hopkins, A. E., 1933. Experiments on the feeding behavior of the oyster, *Ostrea gigas*. *J. Exp. Zool.*, **64**: 469–494.

Hopkins, A. E., 1935. Temperature optima in the feeding mechanism of the oyster, *Ostrea gigas*. *J. Exp. Zool.*, **71**: 195–208.

Jørgensen, C. B., 1949. The rate of feeding by *Mytilus* in different kinds of suspension. *J. Mar. Biol. Ass.*, **28**: 333–344.

Jørgensen, C. B., 1952. On the relation between water transport and food requirements in some marine filter-feeding invertebrates. *Biol. Bull.*, **103**: 356–363.

Jørgensen, C. B., 1955. Quantitative aspects of filter-feeding in invertebrates. *Biol. Rev.*, **30**: 391–454.

Loosanoff, V. L., 1950. Rate of water pumping and shell movements of oysters in relation to temperature. *Anat. Rec.*, **108**: 132.

Loosanoff, V. L., 1954. New advances in the study of bivalve larvae. *Amer. Sci.*, **42**: 607–624.

Loosanoff, V. L., and H. C. Davis, 1950. Conditioning *V. mercenaria* for spawning in winter and breeding its larvae in the laboratory. *Biol. Bull.*, **98**: 60–65.

Loosanoff, V. L., and J. B. Engle, 1947. Effect of different concentrations of micro-organisms on the feeding of oysters (*O. virginica*). *Fish. Bull. 42, U. S. Fish and Wildlife Serv.*, **51**: 31–57.

Loosanoff, V. L., and C. A. Nomejko, 1946. Feeding of oysters in relation to tidal stages and to periods of light and darkness. *Biol. Bull.*, **90**: 244–264.

Moore, H. F., 1910. Volumetric studies of the food and feeding of oysters. *Bull. U. S. Bur. Fish.*, **28**: 1295–1308.

Nelson, T. C., 1935. Water filtration by the oyster and a new hormone effect thereon. *Anat. Rec.*, **64**: 68.

Nelson, T. C., 1936. Water filtration by the oyster and a new hormone effect upon the rate of flow. *Proc. Soc. Exp. Biol.*, **34**: 189–190.

Nelson, T. C., 1938. The feeding mechanism of the oyster. I. *J. Morph.*, **63**: 1–61.

Rao, K. P., 1953. Rate of water propulsion in *Mytilus californianus* as a function of latitude. *Biol. Bull.*, **104**: 171–181.

Verwey, J., 1952. On the ecology of distribution of cockle and mussel in the Dutch Waddensea, their role in sedimentation and the source of their food supply. *Arch. Néerl. de Zool.*, **10**: 172–239.

Wells, W. F., 1926. Conclusions reached by the U. S. Public Health Service in experiments at Fisherman's Island. *Amer. J. of Pub. Health*, **16**: 10–12.

Willemsen, J., 1952. Quantities of water pumped by mussels (*Mytilus edulis*) and cockles (*Cardium edule*). *Arch. Néerl. de Zool.*, **10**: 153–160.

Herring Migrations in the Passamaquoddy Region[1,2]

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ABSTRACT

From June 20 to November 21, 1957, 37,495 herring were tagged in the southern part of the Bay of Fundy and Gulf of Maine. These fish were immature and ranged in total length from 14.2 to 18.7 cm. and in age from 1 to 3 years. Recovery of 792 (2.1%) tagged individuals indicated that the herring moved in and out of Passamaquoddy Bay throughout the summer and early autumn. No interchange of herring took place between Passamaquoddy Bay and the coast of Maine or Nova Scotia. Herring moved into Passamaquoddy from as far south as Grand Manan Island and as far east as Point Lepreau. The greatest straight-line distance moved was 55 miles, the mean time before recapture was 12 days, and the longest time 82 days.

INTRODUCTION

The Passamaquoddy region, located on the southwestern shore of the Bay of Fundy, is the centre of an extensive fishery for young herring. Average annual landings from 1937 to 1956 exceeded 50,000,000 lbs. Primary use of these fish is in the production of canned sardines, though utilization also includes fish meal and oil as well as pet food and bait.

There is no evidence of spawning within the Passamaquoddy region and the exact origin of the young herring supporting this extensive fishery is unknown.

Huntsman (1933, 1934) emphasized the importance of hydrographic conditions to the abundance and movements of herring in this area. As herring were taken in stationary brush weirs, Huntsman considered capture as evidence of movement and suggested that herring "be treated as a planktonic form". He concluded that water movements were responsible for carrying the herring into the region and effecting their distribution there.

To provide specific details of young herring movements, a joint tagging experiment was initiated in 1957 by the Fisheries Research Board of Canada and the United States Fish and Wildlife Service. The purpose of this paper is to present the results of the experiment and to discuss the significance of herring movements in relation to time, direction and distance.

MATERIALS AND METHODS

THE TAG. To initiate a study using tags on sardines, the following requirements were considered: (1) tags had to be external and attached to the head or

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[2]This paper is based on an investigation carried out jointly by the Fisheries Research Board of Canada and the United States Fish and Wildlife Service.

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tail, parts of the body which are not canned; (2) tags had to be small and very light in weight because of the size of the fish; (3) tags had to be quickly and readily made in the laboratory; (4) tags had to be conspicuous. The tag used by McKenzie (1950) for smelt fulfilled these requirements. It was made of scarlet "celluloid" 0.01 inch (0.25 mm.) thick. Tags of various shapes were cut out and distinctively marked so that different taggings could be identified. Fig. 1 shows the method of attaching a tag to the operculum of a herring.

FIG. 1. Attaching a tag to the operculum of a herring. (From McKenzie and Tibbo, 1958)

PRELIMINARY EXPERIMENTS. To test the suitability of this tag for herring, experiments were carried out in the laboratory at St. Andrews, New Brunswick, beginning in November, 1956, by S. N. Tibbo (unpublished data). Thirty-four herring were tagged and an equal number were kept in the same tank as controls. At the end of the first week 10 tagged fish (29%) and 4 controls had died. At the end of the first month 23 tagged fish (68%) and 11 controls were dead. The experiment was concluded at the end of the second month when 4 tagged fish and 9 controls were still alive. No evidence of tag shedding by live fish was seen.

In a similar experiment at Boothbay Harbor, Maine, B. E. Skud and H. C. Boyar (unpublished data) found that cumulative mortalities, including loss of tags, of 51 tagged fish, were 8%, 55%, 84% and 90% in 12, 24, 36 and 48 days respectively. During the same period, cumulative mortalities of 53 controls

were 0%, 20%, 30% and 30%. No records were kept of tags shed by the live fish in the tanks. The tag, although not ideal, was considered to be useful in short term studies of herring movements.

To test recovery, an experiment was carried out by S. N. Tibbo and R. A. McKenzie (unpublished data) at Connors Bros. sardine canning plant in Blacks Harbour on June 5, 1957. Tags were attached to 350 fish entering the plant. With personnel alerted to spot them, 268 (77%) were returned in 3 days, 206 (59%) in the first 2 hours.

FIELD EXPERIMENTS. Fish for tagging were obtained from commercial fishing operations. Great care was taken in handling the fish to insure their return to the water in the best condition possible. Brails and retainers of smooth nylon netting were used to reduce injury from loss of scales. Fish were out of the water for only a few seconds during actual tagging then quickly returned to a net retainer until about 500 had accumulated. Injured fish were removed and the remainder released as small schools rather than as single individuals.

During most of the taggings, samples of fish were taken from the same lots for age and length analyses. Samples taken within the Passamaquoddy region varied in mean total length from 14.2 to 18.7 cm., and in age from 1 to 3 years. Table I shows the length frequency distribution and mean of each sample obtained.

There was no indication that size variation in the tagged fish influenced the results.

TAGGINGS AND RECAPTURES

From June 20 to November 21, 1957, inclusive, 37,495 "sardine" herring were tagged at 15 locations on 17 occasions (Table II). Eight locations were in or at the mouth of Passamaquoddy Bay, two were 25 and 125 miles westward along the coast of Maine, one about 12 miles eastward along the New Brunswick shore, two off southern Grand Manan and two off western Nova Scotia.

A total of 792 or 2.1% were recovered, 738 with complete and 54 with incomplete data concerning time and place of recapture. Only those with complete information are shown in the Figures or considered later in this account.

Distances from tagging sites to recapture positions were measured in straight lines.

The first 5 taggings shown in Table II and Figures 2, 3, and 4 have already been discussed by McKenzie and Tibbo (1958). This tagging of 10,069 herring from June 20 to August 16, 1957, yielded 245 recaptures, 162 of them within 10 days of tagging and the remainder within 80 days. Sixty-six per cent of the recaptures were made within 5 miles of the tagging sites, the others were taken at distances up to 35 miles from the points of release. Some of the recaptures made 30–35 miles away occurred within 6 days of tagging while others were not recovered for 60 days.

Other taggings listed in Table II are described in detail here. Recaptures with incomplete information are not included.

TABLE I. Length-frequency distributions of samples taken from schools of herring that were tagged. Localities marked with an asterisk are outside of the Passamaquoddy region.

Taggings	Length range in millimetres																	
	91–100	101–110	111–120	121–130	131–140	141–150	151–160	161–170	171–180	181–190	191–200	201–210	211–220	221–230	231–240	241–250	251–260	Mean
Moat Island, June 20	...	...	...	...	...	...	2	9	18	11	9	10	5	0	1	1	...	187.0
Harbour de Loutre, June 21	...	...	...	1	15	21	31	24	6	2	...	...	...	...	...	...	...	153.8
Bocabec, July 9	...	...	1	6	32	45	42	37	21	5	1	...	...	...	...	...	...	153.3
New River Beach, July 23	...	1	7	41	55	41	22	18	7	3	4	...	...	...	...	...	...	142.4
Lords Cove, August 22	...	...	...	3	3	19	29	25	10	8	0	1	1	1	...	...	...	160.3
Frost Cove, September 4	1	5	4	8	21	42	41	40	24	6	4	3	0	0	0	1	...	154.6
McDougal's Island, September 5	...	...	5	13	38	53	33	26	17	9	4	1	0	0	1	...	...	151.4
Bucks Harbor,* September 13	...	...	...	1	2	2	10	16	15	19	23	7	3	1	1	...	...	181.4
Harmon Harbor,* October 24	...	2	12	34	44	5	0	2	1	...	...	...	...	...	...	...	...	130.1
Harmon Harbor,* October 30	...	1	6	20	57	7	4	2	1	0	1	1	...	...	...	...	...	146.2
White Head Island,* November 21	...	...	...	...	...	...	...	1	5	18	18	21	14	5	3	...	...	201.0

TABLE II. Recaptures from herring taggings, June 20 to November 21, 1957.

Location	Fish tagged		Recaptures		Total recaptures	
	Date	Number	Complete data	Incomplete data	Number	Per cent
Moat Island	June 20	1,452	13	1	14	0.9
Harbour de Loutre	June 21	1,460	23	7	30	2.1
Bocabec	July 9	2,974	128	22	150	5.0
New River Beach	July 23	2,183	48	10	58	2.7
Pats Cove	Aug. 16	2,000	33	3	36	1.8
Lords Cove	Aug. 21	1,360	39	2	41	3.0
Frost Cove	Sept. 4	2,989	32	1	33	1.1
McDougal's Island	Sept. 5	2,993	61	5	66	2.2
Bucks Harbor	Sept. 13	2,959	2	0	2	0.1
Digby Basin	Sept. 18	1,985	0	0	0	0
Johnson Bay	Oct. 1	2,860	104	3	107	3.7
Bocabec	Oct. 2	2,963	3	0	3	0.1
Cumberland Shore	Oct. 3	2,965	2	0	2	0.1
Harmon Harbor	Oct. 24	461	0	0	0	0
Harmon Harbor	Oct. 30	1,967	250	0	250	12.7
Lear Island	Oct. 30	2,951	0	0	0	0
White Head Island	Nov. 21	973	0	0	0	0
Totals		37,495	738	54	792	2.1

LORDS COVE TAGGING (Fig. 5). On August 21, 1,360 herring were tagged at the Growler weir. Twenty-seven of the recaptures were taken during the first 10 days, 11 within 2 miles of the tagging site, 14 around St. Andrews peninsula and at the head of Passamaquoddy Bay and 2 from Pats Cove, Grand Manan. The remaining 12 recaptures were taken within the next 6 weeks, 2 in the tagging area and 9 at the head of Passamaquoddy Bay. A fairly rapid movement away from the tagging area to the inner part of Passamaquoddy Bay was indicated by these recaptures.

FROST COVE TAGGING (Fig. 6B). On September 4, 2,989 herring were tagged at the Edgar Ritchie weir in Frost Cove, Maine. All recaptures were made more than 2 miles from the tagging site. During the first 10 days following tagging, 20 were recaptured—16 around St. Andrews peninsula and the St. Croix River west of St. Andrews, 3 on the east side of Passamaquoddy Bay and 1 near Lepreau. Of the remainder, 11 were recaptured within another month in the regions indicated above, while 1 was recaptured in Cobscook Bay. Here again, the movement was chiefly to the head of Passamaquoddy Bay with many returns from the St. Andrews peninsula.

MCDOUGAL'S ISLAND TAGGING (Fig. 6A). On September 5, 2,993 herring were tagged at the McDougal's Island weir. Thirty-eight were recaught in the first 10-day period—16 within 2 miles of the tagging site and 22 up to 20 miles away. Fifteen of the 22 were recaptured westward as far as St. Andrews Point and 7 along the shore towards Point Lepreau. The other 23 recaptures were taken during the next 3 weeks—5 within the tagging region and 18 outside of it, all westward around the head of Passamaquoddy Bay as far as St. Andrews. While most of the recaptures were thus from the head of the Bay, a few were from the Bay of Fundy shore almost to Point Lepreau.

FIG. 2. A. Recaptures of herring tagged at Moat Island on June 20. B. Recaptures of herring tagged at Harbour de Loutre on June 21.

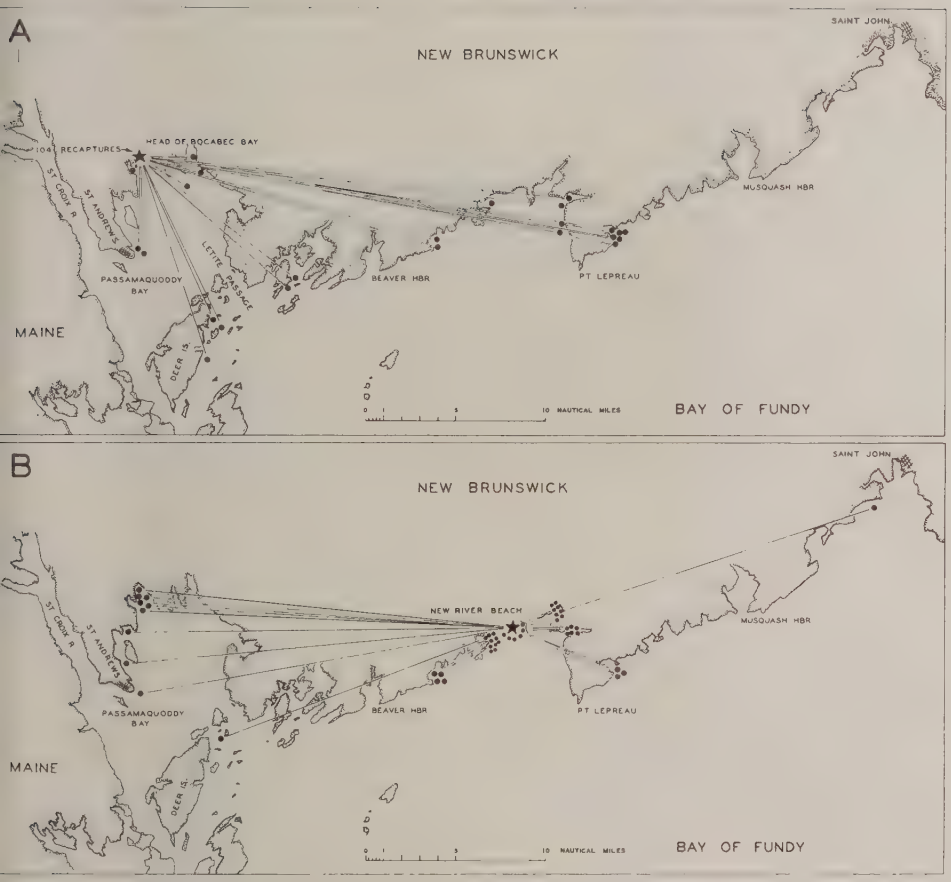

FIG. 3. A. Recaptures of herring tagged at Bocabec on July 9. B. Recaptures of herring tagged at New River Beach on July 23.

FIG. 4. Recaptures of herring tagged at Pats Cove, G.M., on August 16.

FIG. 5. Recaptures of herring tagged at Lords Cove, August 21; Bocabec, October 2; Bucks Harbor, September 13; Cumberland Shore, October 3.

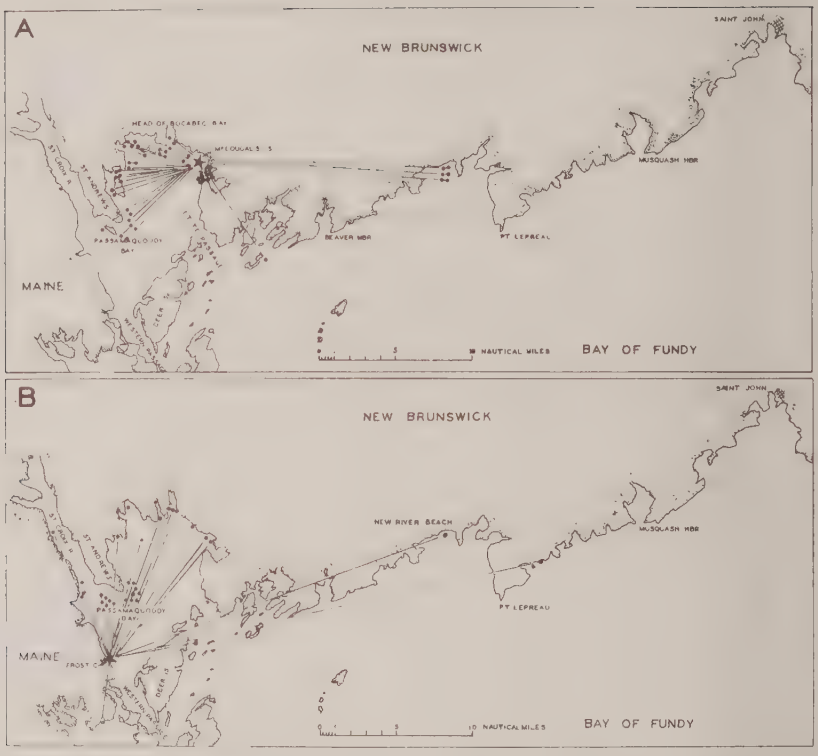

FIG. 6. A. Recaptures of herring tagged at McDougal's Island, September 5. B. Recaptures of herring tagged at Frost Cove, September 4.

BUCKS HARBOR TAGGING (Fig. 5). On September 13, 2,959 herring were tagged on the southwest side of Bar Island in Bucks Harbor, Maine, about 25 miles west of Passamaquoddy Bay. Only 2 recaptures were made—1 not far from the tagging site, while the other was retaken about 50 miles eastward towards Saint John in Lepreau Harbour.

JOHNSON BAY TAGGING (Fig. 7). On October 1, 2,860 herring were tagged at the Jesse Tucker weir, in Johnson Bay, Lubec, Maine. Of the 92 recaptured during the first 10 days, 87 were taken at the tagging site, the other 5 in Cobscook Bay, 6 to 7 miles away. The remaining 12 recaptures were made in the next 2 weeks—4 at the tagging site, 1 in Cobscook Bay, 6 at the head of Passamaquoddy Bay and 1 in Musquash Harbour to the eastward near Saint John. In this tagging also, the movement was into the Cobscook-Passamaquoddy area and to the head of the latter bay.

BOCABEC TAGGING (Fig. 5). On October 2, 2,963 herring were tagged at the Apple Tree weir in the head of Bocabec or Big Bay. The 3 recoveries were within 2 days of tagging and in adjacent weirs.

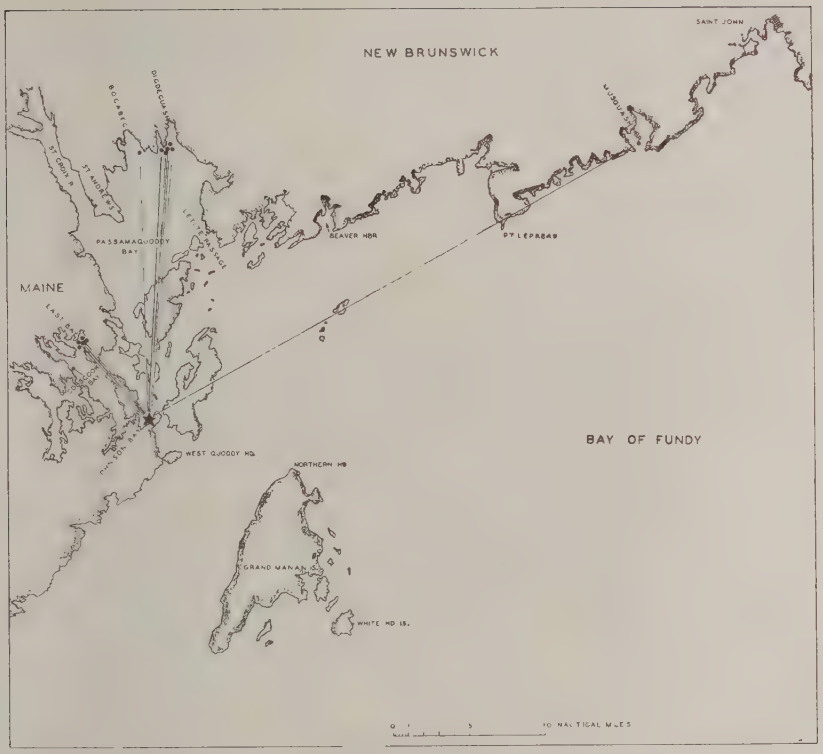

FIG. 7. Recaptures of herring tagged at Johnson Bay, October 1.

CUMBERLAND SHORE TAGGING (Fig. 5). On October 3, 2,965 herring were tagged at the Cumberland Shore weir off Frye or Cailiff Island. Only 2 recaptures were made, both in Musquash Harbour near Saint John, about 25 miles from the tagging site.

HARMON HARBOR TAGGING. No recoveries were made from 461 tagged herring released at Harmon Harbor, Maine, on October 24. However, 250 recoveries were made after a second tagging of 1967 fish on October 30. All recoveries were made on November 6 within a mile of the point of release. Local fishermen believed that strong on-shore winds held fish of the latter tagging in the Bay, whereas offshore winds after the first tagging did not prevent movement out of the bay. Two tag patterns were used in the second tagging and 972 and 995 fish were released. Fish tagged with one pattern were held for at least an hour and released in lots of about 500; fish tagged with the other pattern were held for not more than 10 minutes and released in lots of 25. The number of recoveries was 125 for each pattern and indicated no difference in rate of recapture.

ADDITIONAL TAGGINGS. No recaptures were recorded from 1,985 herring tagged at Digby Basin, N.S., September 18; 2,951 at Lear Island, N.S., near Pubnico,

October 30; and 973 tagged at White Head Island, Grand Manan, November 21. The fact that herring fishing ended in each of these localities soon after tagging probably accounts for the lack of recoveries.

DISCUSSION

Recaptures were considered from the point of view of the distance and direction that the tagged herring moved and the length of time between tagging and recapture. In Tables III, IV, and V and the following discussions, 44 recaptures from the Johnson Bay and 250 recaptures from the Harmon Harbor taggings have not been included because the former were recaught where released within a day and the latter were recaught where released within a week. Other taggings showed that total recoveries varied from 0.1 to 5.0%. Low percentage recoveries may be attributed to tagging late in the fishing season. On the other hand, high percentage returns were made in areas where the concentration of fishing gear was high and the major portions of the catches were made.

EXTENT OF MOVEMENT. Table III shows that 64.2% of the recaptures were made within 5 miles of the points of release. Beyond this distance, the recaptures

TABLE III. Recaptures of tagged herring at 5-mile intervals from points of release.

	Distance, 5-mile intervals												
Taggings	0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–45	45–50	50–55	55–60	Totals
Moat Island	4	7	0	0	0	1	1	...	...	...	...	...	13
Harbour de Loutre	12	3	0	7	1	0	0	...	...	...	...	...	23
Bocabec	108	2	5	3	4	6	0	...	...	...	...	...	128
New River Beach	30	7	0	1	10	0	0	...	...	...	...	...	48
Pats Cove	7	8	0	0	4	4	9	1	...	...	...	...	33
Lords Cove	13	24	0	0	2	...	...	...	...	...	...	...	39
Frost Cove	18	4	8	0	1	1	...	...	...	...	...	...	32
McDougal's Island	42	13	0	6	...	...	...	...	...	...	...	...	61
Bucks Harbor	1	0	0	0	0	0	0	0	0	0	1	...	2
Johnson Bay	47	6	0	6	0	0	0	1	...	...	...	...	60
Bocabec	3	...	...	...	...	...	...	...	...	...	...	...	3
Cumberland Shore	0	0	0	0	0	2	...	...	...	...	...	...	2
Totals	285	74	13	23	22	14	10	2	0	0	1	...	444
Percentage	64.2	16.7	2.9	5.2	5.0	3.2	2.3	0.5	0	0	0.2	...	

TABLE IV. Recaptures of herring made inside and outside of the tagging areas, by 10-day periods.

10-day periods	Recaptures inside (less than 2½ miles)	Recaptures outside (more than 2½ miles)
	no.	*no.*
1st	206	94
2nd	27	60
3rd	15	25
4th to 9th	0	17
Total	248	196

TABLE V. Recaptures of tagged herring at 10-day intervals following tagging.

Taggings	Recaptures per 10-day period									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	Total
Moat Island	0	6	5	0	0	1	0	0	1	13
Harbour de Loutre	8	12	3	...	...	...	...	...	...	23
Bocabec	101	22	2	1	2	...	...	...	...	128
New River Beach	33	7	6	0	0	0	2	...	...	48
Pats Cove	20	6	3	2	0	0	0	2	...	33
Lords Cove	27	3	4	0	4	1	...	...	...	39
Frost Cove	20	9	2	1	...	...	...	...	...	32
McDougal's Island	38	13	10	...	...	...	...	...	...	61
Bucks Harbor	0	2	...	...	...	...	...	...	...	2
Johnson Bay	48	7	5	...	...	...	...	...	...	60
Bocabec	3	...	...	...	...	...	...	...	...	3
Cumberland Shore	2	...	...	...	...	...	...	...	...	2
Totals	300	87	40	4	6	2	2	2	1	444
Percentage	67.6	19.6	9.0	0.9	1.4	0.4	0.4	0.4	0.2	

declined sharply. Only 6.2% were recaptured over 25 miles away. One recapture was made as far away as 55 miles—Bucks Harbor, Maine, to Lepreau Basin, New Brunswick. In some cases, these greater distances were travelled within 6 days of tagging, in others it took as much as 60 days, but, on the average, recapture occurred in 18 days. Of the 285 recaptures within 5 miles of the point of release, 248 were taken within 2½ miles. Table IV shows that in the first 10 days only 31.3% of the recaptures were made beyond 2½ miles of the tagging sites. This percentage increased during successive 10-day periods. After 30 days all recaptures were made beyond 2½ miles.

DIRECTION OF MOVEMENT. There was no apparent seasonal change in the directional movement of the tagged herring. Movements away from the tagging sites were generally not in a single direction. Throughout the summer and autumn months, fish moved both into and out of Passamaquoddy Bay.

Movement into the Bay occurred from points as far east as Point Lepreau and from Grand Manan Island to the south. Of the fish tagged west of West Quoddy Head on the Maine coast, only one was recovered east of Passamaquoddy Bay (Fig. 5). Recoveries in Letite and Western Passages were too few to determine which Passage was used to enter Passamaquoddy Bay. However, the scattering of recoveries made in and about Letite Passage indicated a possible preference for it over Western Passage.

Most recoveries from releases inside Passamaquoddy Bay were made within the Bay itself, in the vicinity of Letite Passage, and east along the mainland shore as far as Saint John. Only two recoveries were made southward to Grand Manan Island and no recoveries were made westward along the coast of Maine. Again, the pattern of recoveries does not indicate clearly whether egress from the Bay was through the Letite or Western Passage.

There were no recoveries in the Passamaquoddy region from taggings carried out in Nova Scotia.

If we assume that the movement of the individuals was not altered by taggings, then the pattern of recoveries suggests that the herring were moving back and forth within the Passamaquoddy region.

DAYS TO RECAPTURE. There was considerable variation in time between tagging and recapture. Over 67% of recaptures were made within the first 10 days, 20% during the next, 9% in the next, and the remainder spread over another 60 days (Table V).

Comparison of the time between release and recovery has been restricted as indicated earlier, and also to experiments which had 10 or more recoveries. The maximum period before recovery was 82 days. In all but one experiment, the mean number of days before recapture ranged from 9 to 15 days. For the exception (Moat Island) the mean was 28 days for the 13 recaptures. Two of these recoveries were made more than 60 days later. The mean number of days from release to recapture for all of the experiments was 12 days. This short period could have been the result of such factors as early loss of tags, tagging mortality or emigration of the tagged fish from the fishing areas. There was no evidence that the tagged fish did emigrate, but laboratory experiments did show high handling and tagging mortality.

As time went on recoveries were not always made progressively farther from the point of release. For example, in the July 9 experiment at Bocabec Bay, one recovery was made as far east as Point Lepreau in 8 days, whereas on July 30 another was made near the tagging site. This phenomenon was repeated in several experiments. Recovery data do not show whether individuals had moved considerable distances and returned to the point of release or whether they had remained in the general vicinity. In many cases, the time lapse was considered great enough for wanderers to have returned to the release site.

SUMMARY

In general the purpose of tagging herring has been to study long distance movements of adult fish. Passamaquoddy taggings provide data on the local movements of immature herring, 1 to 3 years old. Tagging 37,495 of these sardine herring with operculum tags in the southern part of the Bay of Fundy and the Gulf of Maine yielded 792 or 2.1% recoveries. Nearly 50% of the total recaptures were made within 2½ miles and during the first 10 days. Remaining recaptures were spread over distances up to 55 miles, some of which were made within 6 days, some not for 82 days. The mean time from release to recapture was 12 days.

Movements were generally directed in a quadrant extending from the tagging site. Recaptures from taggings inside Passamaquoddy Bay show that movements were mainly to points within the Bay with some towards Letite Passage and as far eastward as Saint John. Recaptures from taggings outside the Bay showed a dominant movement to the head of the Bay with some towards Letite Passage and Point Lepreau. In addition, recaptures from the Grand Manan tagging indicated a movement along the southeastern shore of Grand

Manan as well as westward along the coast of Maine. Though the recoveries indicated considerable movement in the Passamaquoddy region, fish tagged in the Bay were generally recaptured inside, while fish tagged outside also yielded a preponderance of recoveries inside. In addition, the heavy fishery carried on during most of the summer and autumn at the head of the Bay also indicated a concentration of herring there.

Recaptures were made in the Letite area while none were made in Western Passage. This indicated a possible preference for Letite over Western Passage as a means of entering or leaving the Bay.

Apparently no interchange took place between Passamaquoddy Bay and the Nova Scotian shore of the Bay of Fundy. Neither was there any movement from Passamaquoddy Bay to the coast of Maine, but there were 3 recoveries from the Grand Manan tagging along the Maine coast and a single recovery from tagging on the Maine coast eastward at Point Lepreau.

ACKNOWLEDGMENTS

We wish to acknowledge the co-operation of the sardine fishermen and the various plant operators for the return of the tags. We are grateful to the various Canadian Fisheries Officers, especially K. E. Bates, J. P. Cowie, F. W. Durant, and W. C. Hodges, for the purchase and careful recording of tags. Recording of returns in the United States was handled by H. C. Boyar and J. P. Wentworth.

The authors appreciate the extra time and effort given and the enthusiasm with which the technical personnel of the Herring Investigation of the Fisheries Research Board of St. Andrews, N.B., and the U.S. Fish and Wildlife Service at Boothbay Harbor, Maine, carried out the field program.

REFERENCES

Huntsman, A. G. 1933. Mackerel invade the herring nursery. *Biol. Bd. Canada, Atlantic Prog. Rept.*, No. 8, pp. 4–6.

1934. Herring and water movement. James Johnstone Memorial Volume, pp. 81–96.

McKenzie, R. A. 1950. A new celluloid opercular tag. *Trans. Amer. Fish. Soc.* for 1948, 78: 114–116.

McKenzie, R. A., and S. N. Tibbo. 1958. Herring tagging in the Bay of Fundy (June to August 1957). *Fish. Res. Bd. Canada, Atlantic Prog. Rept.* (In press).

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RECORD OF A HATCHERY-REARED RAINBOW TROUT, *SALMO GAIRDNERI GAIRDNERI*, WITH THREE PELVIC FINS.—On April 26, 1954 at the U. S. Fish and Wildlife Service Fish Cultural Station, Winthrop, Washington, a yearling rainbow trout was found which had three pelvic fins. In formalin it was 16.9 cm. in total length. The third pelvic fin was located between the normally placed pelvics, and appeared to be normal in every respect. The pelvic girdle appeared normal in the X-rays.

The specimen, X-rays, and photographs have been deposited in the U. S. National Museum, Washington, D. C., No. 174970.—GALEN H. MAXFIELD, *U. S. Fish and Wildlife Service, Seattle, Washington.*

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roduction of Large Amounts of Pure Water

enneth T. Marvin and Larence M. Lansford, U. S. Fish and Wildlife Service, Galveston, Tex.

DISTILLED WATER of high purity is required for investigating the hemistry of the nutrients and trace lements in sea water. It is needed in rge quantity where much experimental ulture work using artificial sea water in progress. To meet this demand, he Gulf Fishery Investigations labora- ory has constructed a pair of all-glass ills. Operating in tandem, these will roduce in excess of 50 gallons a day of ouble-distilled water having a specific onductivity of 0.7×10^{-6} mho.

This water is used in preparing ulture and nutrient solutions, running hemical analyses, and, equally im- ortant, in cleaning laboratory glass- are.

A diagram of the two stills is shown in igure 1. Borosilicate glass construc- on is used throughout. The boilers, , consist of 72,000-ml. flasks with 02/75 socket neck joints, *C*. Adapters, , connect the 7-foot columns, *G*, to he boilers. The adapters and columns re made of 3-inch glass pipe, held together with glass pipe connecting clamps, *E*. The columns are packed with borosilicate Raschig rings, held in place with retaining plates, *F*, constructed of block tin or high temperature polyethylene (1/4 inch thick). These are profusely perforated with 1/4-inch holes. The top of the columns connect to the heat exchangers, *K*, by connecting arms, *I*. These are made of 1-inch glass pipe with 35/25 socket joints on each end as shown (*H* and *J*) and are wrapped with 700-watt Briskeat heating tapes. The heat exchangers are high speed condensers similar to H. S. Martin's Catalog No. M-7032 but are twice as long and have 35/25 socket joints as shown.

Each still contains a siphon tube, *B*, made of block tin or high temperature polyethylene tubing, which enters the system through one of the six entrance holes in adapter *D*. Electrical conductors *T*, conductor braces *U*, and water inlet *O* also pass through this adapter. The first still contains two $2\ 3/4 \times 6$ inch carbon electrodes, *A*, and the second, a heating coil, *R*, made by winding 17 feet of 0.051-gage Alloy K (C. O. Jelliff Mfg. Corp., Southport, Conn.) on a 1/2-inch mandrel. The condensate from each condenser is conducted to storage tanks, *M* (53.5-gallon polyethylene drums, obtained from A. Daigger and Co., Chicago 10, Ill.), by means of polyethylene pipes, *L*, each of which contains a steam vent, *S*.

The operation of the first still depends upon direct conduction of electricity through the water in the boiling pot. Initially, the pot water must be fortified with enough sodium chloride to permit passage of a desired amount of current. Enough salt solution is added through *B*, so that at a water temperature equal to room temperature, or perhaps slightly higher, the conductivity will be increased sufficiently to permit passage of 25 to 30 amperes under a potential pressure of 220 volts. As the temperature increases to boiling, the conductivity also increases. The final current can be controlled by adjusting the level of the siphon overflow, *N*. The water

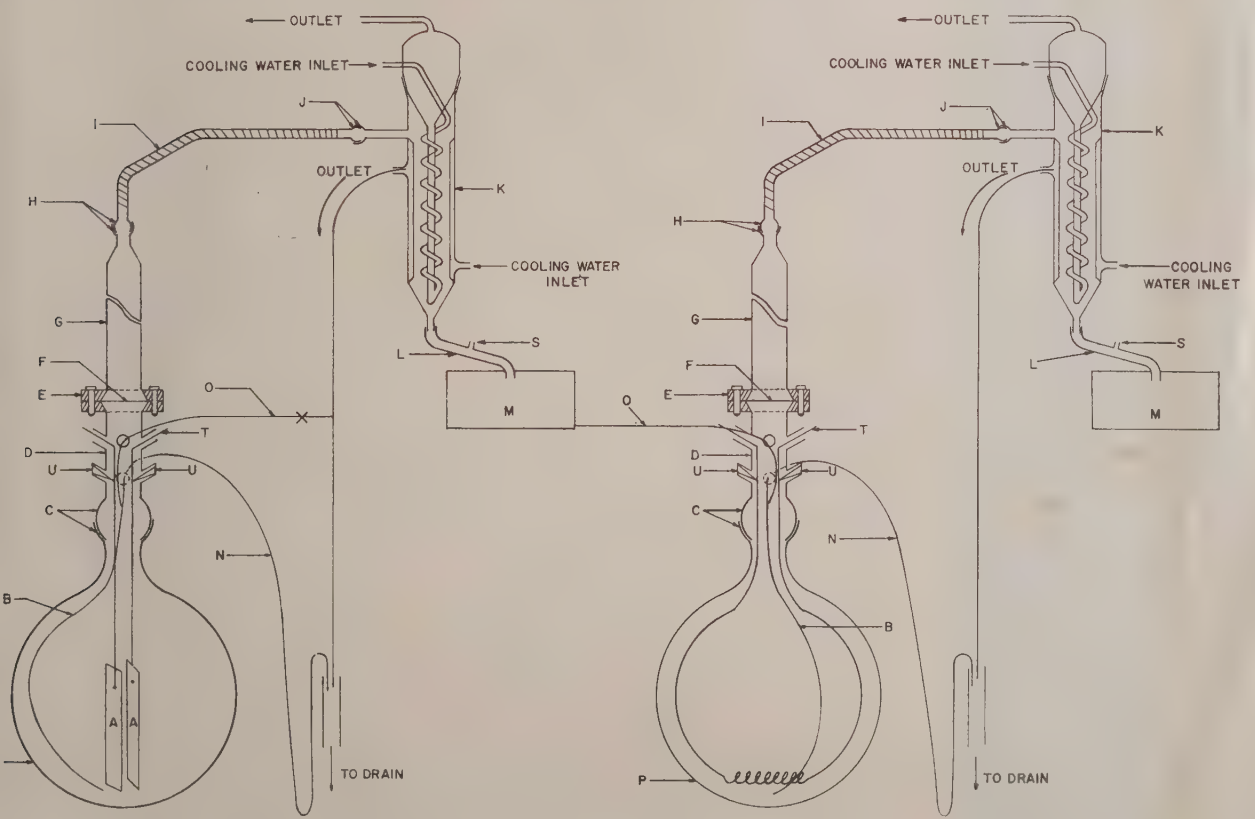

Figure 1. Diagram of two stills

input through O should be slightly greater than the production of distilled water. This will prevent excessive accumulation of solids in the boiling pot and permit the siphon regulator to maintain suitable equilibrium conditions for long periods of time without attention.

Electrolytic action of the raw water in the first still necessitates the use of carbon electrodes. These simplify the maintenance of a constant water level. As the level tends to increase, the resulting increase in current consumption builds up the internal steam pressure in the system. This, in turn, increases the flow of water through the siphon until equilibrium conditions are attained. Similarly, the reverse of these conditions tends to prevent the level from dropping.

As recommended by Ballentine [ANAL. CHEM. 26, 549 (1954)], the two connecting arms, I, are wrapped with flexible heating tapes to prevent formation of water films that might carry impurities into the condensers.

The rate of flow of cooling water through the condensers is regulated so that the condensate emerges with a fair amount of vapor, which escapes through S, carrying with it much of the volatile impurities. The outlet water from the condenser is tapped just before entering the drain to provide a warm water feed source for the boiling pot. The feed water, on entering the boiling pot, must be allowed to run down the siphon tube. This prevents vapor locking within the tube, which would prevent siphon regulation.

The storage tank, M, supplies water to the second still. This is identical to the first, with the exception of the heating element, R. This consists of a coil of resistance wire which limits current consumption to about 40 amperes at 220 volts. As current through this coil is in no way dependent upon the liquid level in the boiling pot, the regulation of the siphon is not so precise as in the first still. However, if the flow rate through O is adjusted so that it is about 1 or 2% greater than that of the output, a fairly constant level can be maintained. The pot is cleaned whenever the distillate conductivity rises above about 0.8×10^{-6} mho. Every 24 hours potassium permanganate is added to oxidize any organic impurities. No special provision has been made for the removal of carbon dioxide.

The rate of production of the first still at a current consumption of 70 amperes at 220 volts is about 5 gallons per hour of distillate having a conductivity of approximately 1.3×10^{-6} mho, and that of the second, at a current consumption of 40 amperes at the same voltage, is just under 2.5 gallons per hour of distillate having a conductivity of about 0.7×10^{-6} mho. The excess water from the first still is used wherever high purity distillate is not required.

If an attempt is made to increase current consumption in the first still, the column may flood and seriously impair the purity of the product. Operating at the suggested amperages, the product of the second still compares favorably with that of smaller all-glass laboratory stills having outputs of 1 to 2 liters per hour and no special provision for elimination of carbon dioxide.

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Recent Maine Records of the Bottlenose Porpoise and the Beguła

By Donald F. Mairs and Leslie W. Scattergood
U. S. Fish and Wildlife Service
Boothbay Harbor, Maine

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Recent Maine Records of the Bottlenose Porpoise and the Beguła

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Along the Maine coast there are occasional strandings or captures of the smaller cetaceans or toothed whales, but the specific identities of these animals are seldom determined. Usually a newspaper report, sometimes accompanied by an indistinct photograph, is our only record. Consequently, our knowledge of the occurrence of these marine mammals is rather limited. Recently, we have had the opportunity to observe two species that we consider to be not common in Maine waters. We feel that, if there were more persons interested in whale identification, neither of these species would be quite as rare as the records indicate.

On April 24, 1956, Scattergood examined a ten-foot bottlenose porpoise, *Tursiops truncatus* (Montague), that had stranded and died in a small brook at the northern end of Sullivan Harbor, Hancock County. This was a non-pregnant female. Since smelts were running in the brooks at this time, the local residents believed that the whale had become stranded while chasing these fish. The stomach, however, was empty.

Fig. 1. Bottle-nose porpoise caught at Sullivan Maine April 24, 1956.

According to Miller and Kellogg (1955, U.S. Nat. Mus. Bull. 205:659) this cetacean's range in the western North Atlantic is from Massachusetts south to Florida. In eastern Canada, there appears to be but one record (Sergeant and Fisher, 1957, Jour. Fish. Res. Bd. Can., 14(1):-93). In Maine, Norton (1930, Proc. Portland Soc. Nat. Hist., 4(1):99-

100) believed this was an abundant coastal species; his opinion was based on sight records only. Our observations in recent years indicate that the common dolphin *Delphinus delphis* L. is often seen along the Maine coast, but we have made no sight records of *Tursiops*. Packard (1958, Maine Field Observer, 3(1):9), reported the occurrence of a *Tursiops* off Harpswell in January 1958. With the present incomplete state of knowledge about marine mammals in this area, we can only offer our opinion that *Tursiops* appears to be unusual, but we would not be greatly surprised if it were locally abundant during some years.

On April 30, 1954, Mairs observed a white whale or beluga, *Delphinapterus leucas* (Pallas) in the Penobscot River at the Bangor Salmon Pool. He watched this whale, which appeared to be about fourteen feet long, for over an hour. At intervals of four or five minutes the animal would surface, usually remaining in view from five to fifteen seconds. The whale appeared in the area of the Salmon Pool on April 26; by May 5 it had disappeared (Portland Press Herald, May 6, 1954). During that period, hundreds of persons flocked to the Pool to see the creature, and it was a popular news item (Bangor Daily News, April 27 and 28, 1954). At the time of Mairs' observation, over forty cars were parked near the river's edge, and minor traffic jams were formed several times by the large number of onlookers during the animal's stay in the area. As in the case of the bottlenose porpoise, many people believed that the beluga was eating the smelts that were on their spawning migrations in the river; there was, however, no evidence that this was true.

Some persons who visited the pool to see the whale were under the impression that several animals were present, and estimates ranged as high as six. At no time did Mairs observe more than one, although several times the animal appeared at quite widely spaced locations on adjacent surfacings. The swimming speed of the animal under water could account for this effect. Dr. Albert A. Barden, Jr. of the University of Maine, who watched the whale on several occasions, has written that he did not see more than one beluga at the surface at any one time.

White whales are not commonly found in Maine waters. True (1889, U. S. Nat. Mus. Bull. 36:188) stated that specimens may straggle south to Cape Cod, Massachusetts, but the species is most abundant in the Arctic and sub-Arctic seas. Sergeant and Fisher (op. cit: 92) mentioned that almost every year fishermen report seeing one to several white whales in the Bay of Fundy; however, these mammals are much less common on the Maine coast. Norton (op. cit:103-104) believed that it was an occasional visitant and stated that one or more specimens had been reported from the vicinity of Casco Bay during the years 1892 or 1893,

1904, 1906, 1907, and 1916. He has documented the 1927 and 1928 appearances of the beluga in that area, and to his account we can add that Elroy Johnson, a Bailey Island fisherman, has told us that on August 30, 1927, he tried to harpoon three or four belugas in Diamond Island Roads, Casco Bay. Later that summer, he also observed the same number near Mackerel Cove, Bailey Island. Lester Stubbs, retired Maine Department of Sea and Shore Fisheries warden, has told us that he saw a specimen in the Penobscot River near Hampden during a summer in the 1930s.

Since these white whales are rather spectacular animals, it appears probable that their appearances would be reported by fishermen and recorded in newspapers. On the other hand, fishermen would consider the bottlenose porpoise to be a "blackfish," "dolphin," or "large porpoise," and therefore not worthy of any particular comment.

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11

A Catalog of the Type Specimens of Fishes Formerly in the Collections of the Department of Tropical Research, New York Zoological Society[1]

GILES W. MEAD[2]

DURING the past thirty-five years the Department of Tropical Research of the New York Zoological Society, under the direction of Dr. William Beebe, has contributed much to the study of fishes. The active field program resulted in large collections which were maintained and studied in the Department's laboratory in the Zoological Park and in a long series of technical publications. In recent years, Dr. Beebe has donated parts of this collection to several institutions, where they continue to contribute to ichthyological research. The distribution of the Department's collection of fishes was completed in 1957 with the transfer of the remaining specimens to the U. S. National Museum and the Natural History Museum, Stanford University. The type material resulting from the Department's work is now in the collections of these two institutions and four others to which specimens were given prior to 1957.

The list which follows has been prepared, at Dr. Beebe's request, primarily to make known the present location of this type material. Its compilation was simplified by the catalogs and indices maintained by Dr. Beebe and through the cooperation of the curators of the several museums that now contain collections assembled by the Department of Tropical Research.

The list is alphabetical, and all species are listed under the genus in which they were first described, regardless of subsequent transfer. Four species of deep-sea fishes were described by Dr. Beebe from sight observations from the bathysphere. These four, *Bathysphaera intacta* (Beebe, 1932, Bull. New York Zool. Soc., 35 (5): 175), *Bathyceratias trilychnus, Bathyembryx istiophasma* and *Bathysidus pentagrammus* (Beebe, 1934, *ibid.*, 37 (6): 190-192), have been omitted.

The following abbreviations have been used:

NYZS–New York Zoological Society. KOH–New York Zoological Society number assigned to specimens which were cleared in potassium hydroxide and stained with alizarine for osteological study. USNM–United States National Museum. SU–Natural History Museum, Stanford University. AMNH–American Museum of Natural History. CAS–California Academy of Sciences.

Acanthemblemaria arborescens Beebe & Tee-Van, 1928, Zoologica (N.Y.), 10 (1): 244. Lamentin Reef, Port-au-Prince Bay, Haiti; Feb. 22, 1927. Type: (NYZS 6923) USNM 170566.

Acanthemblemaria crockeri Beebe & Tee-Van, 1938, *ibid.*, 23 (3): 310. San Lucas Bay, Lower California, Mexico; April 2, 1936. Type: (NYZS 24824) SU 46497.

Acanthemblemaria variegata Beebe & Tee-Van, 1928, *ibid.*, 10 (1): 247. Lamentin Reef, Port-au-Prince Bay, Haiti; May 8, 1927. Type: (NYZS 7464) USNM 170569.

Aceratias edentula Beebe, 1932, *ibid.*, 13 (4): 102. 13 mi. south of Nonsuch, Bermuda; 1,000 fms.; June 2, 1931. Type: (NYZS 20571, misprinted as 20751 in text; KOH 871) USNM 170951.

Ammodytes lucasanus Beebe & Tee-Van, 1938, *ibid.*, 23 (3): 306. Cape San Lucas, Lower California, Mexico; April 25, 1936; from stomach of *Euthynnus alletterata*. Type: (NYZS 25249-A) SU 46501.

Anomalopterus megalops Beebe, 1933, *ibid.*, 13 (8): 159. 12 mi. south of Nonsuch, Bermuda; 700 fms.; July 10, 1929 (net 280). Type: (NYZS 11456) USNM 170957.

Anchoviella longipinna Beebe & Tee-Van, 1928, *ibid.*, 10 (1): 48. Bizoton, Haiti; April 1, 1927. Type: (NYZS 7460) USNM 170574.

Arenichthys apterus Beebe & Tee-Van, 1938, *ibid.*, 23 (3): 301. Arena Bank, Lower California, Mexico; 23° 29′ 30″ N., 109° 25′ 30″ W.; April 20, 1936. Type: (NYZS 25361) SU 46498.

[1]Contribution No. 990, Department of Tropical Research, New York Zoological Society.

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Aristostomias photodactylus Beebe, 1933, Copeia, 1933 (4) : 171. 10 mi. south of Nonsuch, Bermuda; 700 fms.; June 24, 1929. Type: (NYZS 10932) USNM 170931.

Bathophilus altipinnis Beebe, 1933, *op. cit.,* p. 162. 8 mi. south of Nonsuch, Bermuda; 800 fms.; June 24, 1929. Type: (NYZS 10885) USNM 170926.

Bathytroctes drakei Beebe, 1929, Zoologica (N.Y.), 12 (1): 6. Hudson Gorge; 39° 15′ N., 72° 00′ W.; 800 fms.; July 7, 1928. Type: (NYZS 7690) USNM 170958.

Caulolatilus guppyi Beebe & Tee-Van, 1937, *ibid.,* 22 (1): 93. Port of Spain market, Trinidad; Dec. 16, 1936. Type: (NYZS 24737) USNM 170565.

Cetomimus craneae Harry, 1952, *ibid.,* 37 (1): 64. South of Nonsuch, Bermuda; 800 fms.; July 8, 1929. Type: (NYZS 11370) SU 17102.

Cetomimus teevani Harry, 1952, *op. cit.,* p. 61. South of Nonsuch, Bermuda; 700 fms.; Sept. 29, 1930. Type: (NYZS 19519) SU 17101.

Chaenophryne crossotus Beebe, 1932, *ibid.,* 13 (4): 83. 8 mi. south of Nonsuch, Bermuda; 500 fms.; June 15, 1931. Type: (NYZS 20809) USNM 170942.

Chaenophryne draco Beebe, 1932, *op. cit.,* p. 84. 10 mi. southeast of Nonsuch, Bermuda; 600 fms.; Aug. 15, 1931. Type: (NYZS 22396) USNM 170943.

Chaenopsis deltarrhis Böhlke, 1957, Proc. Acad. Nat. Sci. Philadelphia, 109: 93. Gorgona Island, Colombia; 2° 57′ 30″ N., 78° 11′ W.; 2-8 fms. Type: (NYZS 28672) SU 49250.

Cherublemma lelepris Trotter, 1926, Zoologica (N.Y.), 8 (3): 119. Pacific off Colombia, 5° 03′ N., 81° 08′ W.; 140 fms. Type: (NYZS 5108) AMNH 8463.

Chirostomias lucidimanus Beebe, 1932, *ibid.,* 13 (4): 52. 10 mi. south of Nonsuch, Bermuda; 500 fms.; Aug. 10, 1931. Type: (NYZS 22200) USNM 170934.

Cichlasoma haitiensis Tee-Van, 1935, *ibid.,* 10 (2): 294. Étang Saumâtre, Cul-de-Sac Plain, Haiti; March 15, 1927. Type: (NYZS 7302) USNM 170907.

Cirrhitichthys corallicola Tee-Van, 1940, *ibid.,* 25 (5) : 58. Gorgona Island, Pacific off Colombia; 2° 58′ N., 78° 11′ W.; March 30, 1938. Type: (NYZS 28710-A) SU 46504.

Citharichthys gordae Beebe & Tee-Van, 1938, *ibid.,* 23 (3): 302. Outer Gorda Bank, Lower California, Mexico; 60 fms.; April 23, 1936. Type (NYZS 25785) SU 46496.

Corythoichthys bermudensis Beebe & Tee-Van, 1932; *ibid.,* 13 (5): 113. Nonsuch Island, Bermuda; Aug. 18, 1930. Type (NYZS 9326) USNM 170913.

Cremnobates argus Beebe & Tee-Van, 1928, *ibid.,* 10 (1): 238. Lamentin Reef, Port-au-Prince Bay, Haiti. Type: (NYZS 7375) USNM 170904.

Cyprinodon bondi Myers, 1935, *ibid.,* 10 (3): 303. Étang Saumâtre, Haiti; Feb. 20, 1933. Type: USNM 100960.

Cypselurus antarei Beebe & Hollister, 1931, *ibid.,* 12 (9): 83. 200 mi. north of Sombrero, B.W.I.; 21° 50′ N., 63° 32′ W.; June 30, 1932. Type: (*Antares* Exp. no. 6) USNM 170921.

Dasyatis pacificus Beebe & Tee-Van, 1941, *ibid.,* 26 (3): 262. Port Parker, Costa Rica; Jan. 22, 1938. Type: (NYZS 26120) AMNH 15661, 15662, 15663 (three pieces of the body) and 15710 (lower jaw).

Diabolidium arcturi Beebe, 1926, Bull. New York Zool. Soc., 29 (2): 80. Pacific; 4° 50′ N., 87° W.; 514-900 fms. Type: (NYZS 6144; number on vial containing type: 6333) SU 46505.

Dicrolene gregoryi Trotter, 1926, Zoologica (N.Y.), 8 (3): 116. Pacific; 4° 50′ N., 87° W.; 844 fms.; May 31, 1925. Type: (NYZS 6063) AMNH 7511.

Dixonina pacifica Beebe, 1942, *ibid.,* 27 (8): 43. Port Culebra, Costa Rica; 10° 31′ N., 85° 40′ W.; Jan. 24, 1938. Type: (NYZS 26131) SU 46486.

Dolichopteryx binocularis Beebe, 1932, *ibid.,* 13 (4): 49. 14 mi. southeast of Nonsuch, Bermuda; 400 fms.; Aug. 4, 1931. Type: (NYZS 21867; KOH 960) USNM 170933.

Dolopichthys gladisfenae Beebe, 1932, *op. cit.,* p. 86. 6 mi. south of Nonsuch, Bermuda; 700 fms.; May 28, 1930. Type: (NYZS 15490) USNM 170944.

Dolopichthys tentaculatus Beebe, 1932, *op. cit.,* p. 88. 10 mi. southeast of Nonsuch, Bermuda; 600 fms.; Sept. 7, 1931. Type: (NYZS 23170) USNM 170945.

Emblemaria micropes Beebe & Tee-Van, 1938, *ibid.,* 23 (3): 308. Inez Point, Santa Inez Bay, Gulf of California, Mexico; April 9, 1936. Type: (NYZS 24895) SU 46499.

Eucinostomus mowbrayi Beebe & Tee-Van, 1932, *ibid.,* 13 (5) : 115. Nonsuch Island, Bermuda; Sept. 30, 1930. Type: (NYZS 9328) USNM 170909.

Eupomacentrus beebei Nichols, 1924, *ibid.,* 5 (4): 63. Eden, Indefatigable Island, Galapagos; April 1, 1923. Type: AMNH 8270.

Eupomacentrus rubridorsalis Beebe & Hollister, 1933, *ibid.,* 12 (9): 85. Chatham Bay, Union Island, Grenadines, B.W.I.; July 9, 1932. Type: (NYZS-*Antares* Exp. no. 97) USNM 170922.

Eustomias satterleei Beebe, 1933, Copeia 1933 (4): 164. 8 mi. south of Nonsuch, Bermuda; 1,000 fms.; Sept. 10, 1929. Type: (NYZS 13457) USNM 170927.

Eustomias schiffi Beebe, 1932, Zoologica (N.Y.), 13 (4): 54. 6 mi. south of Nonsuch, Bermuda; 600 fms.; May 29, 1930. Type: (NYZS 15653) USNM 170935.

Exonautes marginatus Nichols & Breder, 1928, *ibid.,* 8 (7): 429. Pacific east of the Galapagos; 2° 36′–2° 8′ N., 85° 1′–86° 31′ W. Type: AMNH 9234.

Exonautes nonsuchae Beebe & Tee-Van, 1932, *ibid.,* 13 (5): 112. Near St. David's Island, Bermuda; May 15, 1929. Type: (NYZS 9983) USNM 170912.

Gambusia beebei Myers, 1935, *ibid.,* 10 (3): 305. Étang de Miragoâne, Haiti. Type: (NYZS 7168); missing.

Gobiesox daedaleus boreus Briggs, 1955, Stanford Ichthyol. Bull., 6 (1): 111. Conchaguita Island, Gulf of Fonseca, El Salvador; Dec. 22, 1937. Type: (NYZS 27550) SU 17392.

Gobiesox stenocephalus Briggs, 1955, *op. cit.*, p. 92. Puerto Parker, Costa Rica; Jan. 14, 1938. Type: (NYZS 27872) SU 17408.

Gigantactis perlatus Beebe & Crane, 1947, Zoologica (N.Y.), 31 (4): 167. Pacific off Jicaron Island, Panama; 500 fms.; March 20, 1938. Type: (NYZS 28621) SU 46487.

Gillellus quadrocinctus Beebe & Hollister, 1935, *ibid.*, 19 (6): 222. (Also spelled *quadrocintus*, a lapsus). Union Island, Grenadines, B.W.I.; July 12, 1934. Type: (NYZS-*Antares* Exp. no. 180); missing.

Gobiosoma chancei Beebe & Hollister, 1933, *ibid.*, 12 (9): 87. St. George's Bay, Grenada, B.W.I.; July 4, 1932. Type: (NYZS-*Antares* Exp. no. 22) USNM 170955.

Gobiosoma macrodon Beebe & Tee-Van, 1928, *ibid.*, 10 (1): 226. Lamentin Reef, Port-au-Prince Bay, Haiti. Type: (NYZS 7462) USNM 170896.

Haplophryne hudsonius Beebe, 1929, *ibid.*, 12 (2): 23. Hudson Gorge; 600 fms.; July 7, 1928. Type: (NYZS 7696; KOH 26) USNM 170954.

Himantolophus azurlucens Beebe & Crane, 1947, *ibid.*, 31 (4): 155. Pacific off Cape Mala, Panama; 7° N., 79° 16′ W.; 500 fms.; March 25, 1938. Type: (NYZS 28641) SU 46507.

Hypleurochilus bermudensis Beebe & Tee-Van, 1933; *ibid.*, 13 (7): 155. Marshall Island, Bermuda. Type: Harvard Mus. Comp. Zool. no. 33070.

Iridio bathyphilus Beebe & Tee-Van, 1932, *ibid.*, 13 (5): 117. 1 mi. south of Nonsuch, Bermuda; 510 feet; Sept. 30, 1929. Type: (NYZS 9050) USNM 170910.

Labrisomus albigenys Beebe & Tee-Van, 1928, *ibid.*, 10 (1): 233. Lamentin Reef, Port-au-Prince Bay, Haiti; May 9, 1927. Type: (NYZS 7372) USNM 170899.

Labrisomus haitiensis Beebe & Tee-Van, 1928, *op. cit.*, p. 232. Bizoton, Port-au-Prince Bay, Haiti; March 15, 1927. Type: (NYZS 7170) USNM 170903.

Lampanyctus septilucis Beebe, 1932, *ibid.*, 13 (4): 68. 7 mi. south-southwest of Nonsuch, Bermuda; 700 fms.; July 4, 1929. Type: (NYZS 14292-A) USNM 171199.

Lampanyctus polyphotis Beebe, 1932, *op. cit.*, p. 67. 5 mi. south of Nonsuch; 900 fms.; May 25, 1929. Type: (NYZS 10151) USNM 171200.

Lamprotoxus angulifer Beebe, 1932, *op. cit.*, p. 56. 15 mi. southeast of Nonsuch, Bermuda; 500 fms.; July 27, 1931. Type: (NYZS 21667) USNM 170936.

Lasiognathus beebei Regan & Trewavas, 1932. Dana Rep. (1928-30 Exped.), 2: 90. Descr. based on Beebe, Bull. N. Y. Zool. Soc., 33 (2): 60 (figure), without reference to specimen. Figure taken from a specimen which should stand as the type: (NYZS 9804; KOH 287) USNM 170956.

Leptocephalus microphthalmus Beebe & Tee-Van, 1928, Zoologica (N.Y.), 10 (1): 58. Port-au-Prince Bay, Haiti; March 19, 1927. Type: (NYZS 7080) USNM 170906.

Leptophilypnus crocodilus Beebe & Tee-Van, 1928, *op. cit.*, p. 219. Lamentin Reef, Port-au-Prince Bay, Haiti. Type: (NYZS 7467) USNM 170905.

Leptostomias bermudensis Beebe, 1932, *ibid.*, 13 (4): 59. 7½ mi. southeast of Nonsuch, Bermuda; 500 fms.; June 15, 1931. Type: (NYZS 20826) USNM 170937.

Linophryne brevibarbata Beebe, 1932, *op. cit.*, p. 94. 9 mi. southeast of Nonsuch, Bermuda; 900 fms.; July 16, 1929. Type: (NYZS 11656; KOH 973) USNM 170947.

Linophryne quinqueramosus Beebe & Crane, 1947, *ibid.*, 31 (4): 174. Pacific off Panama; 7° 24′ N., 78° 35′ W.; 500 fms.; April 4, 1938. Type: (NYZS 28709) SU 46506.

Lipactis megalops Beebe, 1929, *ibid.*, 12 (1): 19. Hudson Gorge; 1,000 fms.; July 28, 1925. Type: (NYZS 6633-A) missing since prior to 1932.

Lophodolus lyra Beebe, 1932, *ibid.*, 13 (4): 96. 10 mi. south of Nonsuch, Bermuda; 800 fms.; July 27, 1931. Type: (NYZS 21610) USNM 170949.

Macromastax gymnos Beebe, 1933, *ibid.*, 13 (8): 162. 8 mi. south of Nonsuch, Bermuda; 1,000 fms.; June 22, 1929. Type: (NYZS 10829) USNM 170960.

Macrostomias calosoma Beebe, 1933, *op. cit.*, p. 165. 12 mi. southeast of Nonsuch, Bermuda; 600 fms.; Sept. 15, 1930. Type: (NYZS 18781); missing.

Megalodoras irwini Eigenmann, 1925, Trans. American Phil. Soc., n.s., 22 (5): 307-308. Beebe's specimen, Indiana Univ. no. TRS 2567, was made the type of a new species which Eigenmann suppressed in proof when he found it to be a large representative of *M. irwini*, described on the following page. It is evident from his account that he intended a specimen from Iquitos collected by Allen to be the type. Beebe's fish is now in the California Academy of Sciences (CAS 20735).

Melanocetus megalodontis Beebe & Crane, 1947, Zoologica (N.Y.), 31 (4): 152. Pacific 145 mi. north of Clarion Island; 500 fms.; May 17, 1936. Type: (NYZS 25791) SU 46488.

Melanonus unipennis Beebe, *ibid.*, 13 (4): 74. 10 mi. southeast of Nonsuch, Bermuda; 700 fms.; Aug. 15, 1931. Type: (NYZS 22397) USNM 170940.

Melanostomias bulbosus Beebe, 1933, Copeia, 1933 (4): 166. 9 mi. southeast of Nonsuch, Bermuda; 700 fms.; May 30, 1929. Type: (NYZS 10235) USNM 170928.

Mnierpes macrocephalus catherinae Clark Hubbs, 1952, Stanford Ichthyol. Bull., 4 (2): 61. Piedra Blanca, Costa Rica; Feb. 4, 1938. Type: (NYZS 27178, misprinted as 28178) SU 46509.

Mobula lucasana Beebe & Tee-Van, 1938, Zoologica (N.Y.), 23 (3): 299. San Lucas Bay, Lower California, Mexico. Type: (NYZS 24793) AMNH 15676 and 15675 (two pieces).

Neonesthes gnathoprora Cohen, 1956, *ibid.*, 41 (2): 81. South of Nonsuch, Bermuda; 900 fms.; Aug. 17, 1929. Type: (NYZS 12501) SU 46381.

Neonesthes nicholsi Beebe, 1933, Copeia, 1933 (4): 160. 9 mi. south of Nonsuch, Bermuda; 800 fms.; Sept. 1, 1930. Type: (NYZS 17529) USNM 170925.

Ophioblennius ferox Beebe & Tee-Van, 1928, Zoologica (N.Y.), 10 (1): 242. Bizoton, Port-au-Prince Bay, Haiti; April 6, 1927. Type: (NYZS 7152) USNM 170901.

Parabrotula dentiens Beebe, 1932, *ibid.*, 13 (4): 81. 8 mi. southeast of Nonsuch, Bermuda; 800 fms.; June 12, 1930. Type: (NYZS 16110; published error: NYZS 15882; KOH 556) USNM 170952.

Paraclinus beebei Clark Hubbs, 1952, Stanford Ichthyol. Bull., 4 (2): 81. Piedra Bay, Costa Rica. Type: (NYZS 28152) SU 46512.

Pherallodiscus varius Briggs, 1955, *ibid.*, 6 (1): 131. Passavera Island, Chamela Bay, Jalisco, Mexico; Nov. 19, 1937. Type: SU 17807.

Photichthys nonsuchae Beebe, 1932, Zoologica (N.Y.), 13 (4): 61. 7 mi. south-southwest of Nonsuch, Bermuda; 600 fms.; May 3, 1929. Type: (NYZS 9793; published error: NYZS 9973) USNM 170938.

Photonectes bifilifer Beebe, 1933, Copeia, 1933 (4): 167. 9 mi. south of Nonsuch, Bermuda; 800 fms.; May 19, 1930. Type: (NYZS 15146) USNM 170929.

Photonectes cornutus Beebe, 1933, *op. cit.*, p. 169. 10 mi. south of Nonsuch, Bermuda; 600 fms.; Sept. 4, 1930. Type: (NYZS 17875) USNM 170930.

Photostylus pycnopterus Beebe, 1933, Zoologica (N.Y.), 13 (8): 163. 9 mi. southeast of Nonsuch, Bermuda; 800 fms.; May 30, 1929. Type: (NYZS 10217) USNM 170959.

Pomacentrus freemani Beebe & Tee-Van, 1928, *ibid.*, 10 (1): 196. Sand Cay, Port-au-Prince Bay, Haiti; May 7, 1927. Type: (NYZS 7269) USNM 170898.

Prionotus teaguei Briggs, 1956, Quart. Journ. Florida Acad. Sci., 19 (2-3): 101. 14 mi. southeast of Judas Point, Costa Rica; 9° 19′ 32″ N., 84° 29′ 30″ W.; March 1, 1938. Type: SU 46380.

Psammobatus spinosissimus Beebe & Tee-Van, 1941, Zoologica (N.Y.), 26 (3): 259. Pacific south of Cocos Island; 765 fms.; June 3, 1925. Type: (NYZS 6132) SU 46500. Station data given in text do not agree with *Arcturus* station 72, the published number, but with station 74.

Pseudoscopelus stellatus Beebe, 1932, *ibid.*, 13 (4): 75. 8 mi. southeast of Nonsuch, Bermuda; 300 fms.; July 7, 1931. Type: (NYZS 21555) USNM 170941.

Quassiremus goslingi Beebe & Tee-Van, 1932, *ibid.*, 13 (5): 110. Castle Roads, Bermuda; 30 feet; March 21, 1929. Type: (NYZS 8700) USNM 170563.

Runula albolinea Nichols, 1924, *ibid.*, 5 (4): 64. Indefatigable Island, Galapagos. Type: AMNH 8271.

Rypticus bornoi Beebe & Tee-Van, 1928, *ibid.*, 10 (1): 132. Lamentin Reef, Port-au-Prince Bay, Haiti; April 27, 1927. Type: (NYZS 7206) USNM 170572.

Saccopharynx harrisoni Beebe, 1932, *ibid.*, 13 (4): 63. 10 mi. southeast of Nonsuch, Bermuda; 900 fms.; June 11, 1931. Type: (NYZS 20802) USNM 170939.

Scorpaenodes cortezi Beebe & Tee-Van, 1938, *ibid.*, 23 (3): 304. Off San José Island, Gulf of California, Mexico; 24° 55′ N., 110° 20′ W.; April 8, 1936. Type: (NYZS 24889-A) SU 46503.

Scorpaenodes russelli Beebe & Tee-Van, 1928, *ibid.*, 10 (1): 189. Bizoton Reef, Port-au-Prince Bay, Haiti; 12 feet; April 27, 1927. Type: (NYZS 7207) USNM 170573.

Somersia furcata Beebe & Tee-Van, 1934, American Mus. Novitates, 730: 1. Hungry Bay, Bermuda; Nov. 12, 1933. Type: (NYZS 26165) USNM 170924.

Stathmonotus corallicola Beebe & Tee-Van, 1928, Zoologica (N.Y.), 10 (1): 249. Lamentin Reef, Port-au-Prince Bay, Haiti; April 22, 1927. Type: (NYZS 7463) USNM 170571.

Stathmonotus lugubris Böhlke, 1953, *ibid.*, 38 (3): 145. Port Guatulco, Golfo de Tehuantepec, Mexico; 15° 43′ 30″ N., 96° 08′ W.; Dec. 3, 1937. Type: (NYZS 27236) SU 17748.

Stomias fusus Beebe, 1929, *ibid.*, 12 (1): 7. Hudson Gorge; 600 fms.; Aug. 6, 1928. Type: (NYZS 7667) USNM 170953.

Syngnathus mackayi nesiotes Herald, 1942, Stanford Ichthyol. Bull., 4 (2): 128. Nonsuch, Bermuda. Type: (NYZS 8919) USNM 170915.

Syngnathus pipulus Beebe & Tee-Van, 1932, Zoologica (N.Y.), 13 (5): 115. The Reach, Bermuda. Type: (NYZS 25152) USNM 170914.

Tomicodon eos rhadinus Briggs, 1955, Stanford Ichthyol. Bull., 6 (1): 70. Tangola-Tangola Bay, Oaxaca, Mexico; Dec. 12, 1937. Type: (NYZS 27516) SU 18121.

Trematorhynchus adipatus Beebe & Crane, 1947, Zoologica (N.Y.), 31 (4): 163. Pacific 71 mi. off Cape Corrientes, Colombia; 500 fms.; March 26, 1938. Type: (NYZS 28770) SU 46494.

Trematorhynchus moderatus Beebe & Crane, 1947, *op. cit.*, p. 164. Pacific, off Cape Corrientes, Colombia; 500 fms.; March 26, 1938. Type: (NYZS 28771) SU 46492.

Trematorhynchus multilamellatus Beebe & Crane, 1947, *op. cit.*, p. 165. 16 mi. southwest of Narborough Island, Galapagos; 1,900 fms.; June 12, 1925. Type: (NYZS 6321) SU 46490.

Trematorhynchus multiradiatus Beebe & Crane, 1947, *op. cit.*, p. 166. Pacific, 11 mi. southwest of Jicaron Island, Panama; 500 fms.; March 20, 1938. Type: (NYZS 28773) SU 46491.

Trematorhynchus paucilamellatus Beebe & Crane, 1947, *op. cit.*, p. 166. Pacific, 20 mi. south of Cape Blanco, Costa Rica; 500 fms.; Feb. 7, 1938. Type: (NYZS 28250) SU 46489.

Ultimostomias mirabilis Beebe, 1933, Copeia, 1933 (4): 174. 12 mi. south of Nonsuch, Bermuda; 900 fms.; June 24, 1929. Type: (NYZS 10865) USNM 170932.

Xenoceratias nudus Beebe & Crane, 1947, Zoologica (N. Y.), 31 (4): 155. Pacific, 20 mi. south of Cape Blanco, Costa Rica; 500 fms.; Feb. 27, 1938. Type: (NYZS 28402) SU 46495.

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ICHTHYOLOGY.—*A new species of iniomous fish from the Gulf of Mexico.* GILES W. MEAD, United States Fish and Wildlife Service.

(Received April 14, 1958)

The iniomous family Aulopidae is composed of three genera. *Hime* includes *H. japonicus* (Günther, 1880: 72), which is known from various localities in the western Pacific, and *H. damasi* (Tanaka, 1915: 340), from Japan. The Australian *Latropiscis* includes two closely related species, *L. purpurissatus* (Richardson, 1843: 6) and *L. milesi* (Cuvier and Valenciennes, 1849: 521; roy. ed. p. 386). *Aulopus*, heretofore known only from the Mediterranean Sea and adjacent Atlantic waters, includes *A. filamentosus* Cloquet (1816: 128), *A. tirus* (Rafinesque, 1810: 56), *A. lacerta* (Risso, 1826: 463), *A. filifer* Valenciennes (1836: 73), *A. maculatus* Valenciennes (1836: 74), *A. cadenati* Poll (1953: 81) and the new species described below. Although *Aulopus lacerta*, *filifer* and *maculatus* are conventionally included within the synonymy of *A. filamentosus*, such allocation is questionable. Not all of the differences among the published descriptions can be attributed to sexual dimorphism. Material which would permit a review of the eastern Atlantic forms is not now available.

I am indebted to G. E. Maul of the Museu Muncipal do Funchal, Funchal, Madeira; Dr. Enrico Tortonese, Museum of Natural History, Genoa, Italy; and Dr. Max Poll, Musée Royal du Congo Belge, Tervuren, Belgium, for comparative specimens of *Aulopus filamentosus* and *A. cadenati* from off Madeira, Italy, and equatorial Africa.

Aulopus nanae, n. sp.

(Fig. 1; Table 1)

Holotype: A male specimen 223.0 mm in standard length caught in the Gulf of Mexico off Tortugas, Fla., by the United States Fish and Wildlife Service exploratory vessel *Oregon* at station number 1025 (April 19, 1954; 25° 12′ N. lat., 84° 05′ W. long.; 75 fathoms; 40-foot flat shrimp trawl). USNM 158985.

Diagnosis: Similar to the eastern Atlantic *Aulopus filamentosus* but differing principally in the number of predorsal scales (12 *cf.* 15–16 in *A. filamentosus*), number of scales in lateral line (48 *cf.* 52), number of vertebrae (48 including the hypural *cf.* 51–52), the width of the bony interorbital (3.6 percent of standard length *cf.* 4.1–5.0 percent), the length of the ventral fin (27.6 percent *cf.* 19.6–25.6) and the length of the anal fin, the last ray of which is much longer than the depth of the fish measured at origin of anal fin (15.2 percent of standard length *cf.* 7.6–9.6 in eastern Atlantic *A. filamentosus* males; 7.7 in *A. cadenati*).

Description: The counts and proportional measurements of the single known specimen of *Aulopus nanae* are given in the first column of Table 1.

Body subcylindrical, broadest at origin of pectoral fin. Snout depressed, the ventral profile nearly straight from tip of lower jaw to caudal peduncle. Body deepest at origin of dorsal fin, this depth 1.8 in length of head. Depth of body at origin of anal fin 2.6 in head; least depth of caudal peduncle 4.5 in length of head.

Top of head, snout and mandible naked. Cheeks, opercles, body and base of caudal fin scaled. Lateral line complete, terminating over base of micaudal ray and formed of scales each of which bears a simple tube but is otherwise similar to the scales adjacent to the lateral line. Scales on head and sides of body ctenoid, those on ventral surface cycloid. Body scales relatively large and imbricate, the cteni numerous and irregular in size. Scales in axil of pectoral fin lacking cteni and more closely imbricate than body scales but of similar size and shape. Scales in axil of pelvic fin vertically elongate but not greatly enlarged.

Length of head 3.3 in standard length. Length of snout 3.6 in length of head; lower jaw terminal. Nostril located about two-thirds of distance from tip of snout to anterior edge of orbit. Septum between anterior and posterior nostril with a simple cirrus, the length of which is about one-half the width of the bony interorbital. Eye irregularly circular, entering into dorsal profile its horizontal diameter 4.3 in length of head. Iris round. Horizontal diameter of orbit greater than vertical. A notch along lower edge of orbit. Width

TABLE 1.—COUNTS AND PROPORTIONAL MEASUREMENTS (IN PERCENT OF STANDARD LENGTH) TAKEN FROM THE TYPE OF AULOPUS NANAE AND COMPARATIVE EASTERN ATLANTIC SPECIMENS OF A. FILAMENTOSUS AND A. CADENATI

	Aulopus nanae; holotype; USNM 158985; male; Gulf of Mexico	*Aulopus filamentosus;* male; Madeira	*Aulopus filamentosus;* female; Madeira	*Aulopus filamentosus;* male; Azores	*Aulopus cadenati,* paratype R. G. Mus. Congo 95184; female; tropical West Africa	*Aulopus cadenati,* paratype R. G. Mus. Congo 95182–3; male; tropical West Africa
Counts:						
Dorsal fin	15½	16½	15½	15½	14½	14½
Anal fin	12½	12½	11½	11½	11½	12½
Pectoral fin	12/13	13/13	12/13	12/13	13/14	13/13
Ventral fin	9/9	9/9	9/9	9/9	9/9	9/9
Caudal fin	I–17–I	I–17–I	I–17–I	I–17–I	I–17–I	I–17–I
Branchiostegal rays	15/16	16/16	16/16	16/16	15/16	16/16
Gill rakers (first arch)	3+1+10	2+1+11	3+1+10	3+1+10	2+1+10	3+1+9
Vertebrae	47+1	51+1	50+1	50+1	49+1	49+1
Scales in lateral line	48	52	52	52	50	51
Predorsal scales	12	15	15	16	13	13
Measurements:						
Standard length (mm)	223.0	292.0	278.0	217.0	197.0	227.5
Depth at origin of dorsal fin	16.6	18.3	15.5	15.9	16.5	17.9
Depth at origin of anal fin	11.7	11.8	11.3	10.4	11.2	11.8
Depth at origin of adipose fin	9.4	9.9	9.9	9.4	9.8	9.7
Least depth of caudal peduncle	6.6	7.0	6.5	6.9	6.4	6.1
Width of body at pectoral fin base	15.0	14.6	14.9	—	15.8	16.6
Length of head (greatest)	30.0	31.5	30.4	30.4	31.5	32.4
Snout to uppermost point of gill opening	20.6	22.6	22.4	20.6	22.9	22.9
Length of snout	8.3	9.2	9.0	7.8	9.9	9.0
Horizontal diameter of eye	6.9	6.5	6.6	7.4	8.1	8.6
Vertical diameter of eye	6.3	5.3	5.7	6.0	6.5	6.6
Postorbital length of head	15.8	16.3	16.0	15.7	15.9	16.8
Posterior edge of eye to uppermost point of gill opening	5.6	7.2	7.2	6.5	6.0	6.5
Width of bony interorbital	3.6	4.8	4.3	4.1	3.8	4.1
Length of premaxillary	14.6	16.1	15.8	15.7	15.3	15.3
Snout to origin of dorsal fin	36.4	37.7	37.2	36.9	37.6	38.5
Snout to origin of anal fin	68.8	72.8	73.5	73.3	73.9	74.1
Snout to origin of pectoral fin	29.6	31.7	31.5	30.6	32.0	32.5
Snout to origin of ventral fin	34.9	38.7	38.5	36.6	38.1	37.8
Origin of dorsal fin to origin of anal fin	38.3	38.0	37.8	40.4	38.9	39.8
Origin of ventral fin to origin of anal fin	35.6	36.2	36.0	35.9	37.4	36.3
End of base of dorsal fin to origin of anal fin	18.8	19.0	19.2	20.3	20.1	20.2
Anus to origin of anal fin	10.5	9.4	10.1	10.1	10.1	10.8
Length of base of dorsal fin	21.7	21.4	21.1	21.0	20.0	20.2
Length of base of anal fin	13.9	12 5	11.3	11.1	11.5	11.4
Origin of dorsal fin to tip of longest ray (fin depressed)	—	40.4	29.6	33.2	27.4	30.3
Origin of anal fin to tip of longest ray (fin depressed)	29.1	21.1	16.7	19.1	18.0	19.6
Length of second dorsal ray	—	39.4	16.5	28.8	16.2	19.8
Length of penultimate dorsal ray	18.6	15.9	9.9	14.7	9.4	11.9
Length of second anal ray	12.8	11.0	8.6	10.6	8.4	10.3
Length of penultimate anal ray	16.6	9.7	6.5	9.0	6.5	7.9
Length of last anal ray	15.2	9.6	5.8	7.6	6.5	7.7
Length of pectoral fin	—	16.3	14.7	16.6	16.4	16.0
Length of ventral fin	27.6	24.6	19.6	25.6	20.3	20.2

of fleshy interorbital slightly greater than vertical diameter of eye. Width of bony interorbital 1.9 in horizontal diameter of eye. Opercular flap long and thin, extending posteriorly below and beyond origin of pectoral fin, the posterior edge formed by the subopercle.

Maxillary extending to below posterior fourth of eye, its length 2.1 in length of head, expanded posteriorly, and bearing two supramaxillaries, the larger of which overlies the posterior half of the maxillary. Angle of gape below center of eye. Anterior and lateral surfaces of lower jaw rugose.

Teeth on mandible, tongue and premaxillary, vomer, and palatine bones. Symphysis of lower jaw edentulous. Rami with a broad band of pointed, conical teeth which are straight or

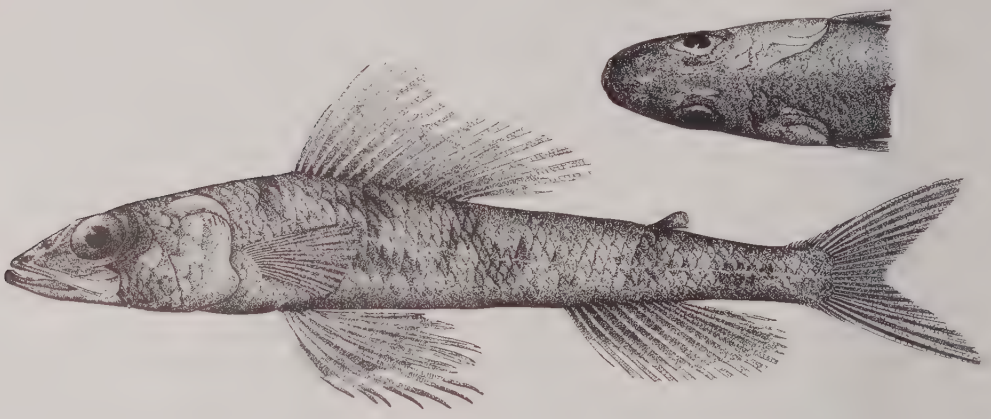

FIGURE 1.—*Aulopus nanae*, holotype, U.S.N.M. 158985. (Drawn by Nancy W. Mead.)

slightly recurved. The inner teeth of this band are longer than the outer, and are depressible. Most of the larger outer mandibular teeth are depressible; the smaller are fixed. A broad longitudinal band of minute teeth on tongue. Teeth on premaxillary in a broad band similar to those on the mandible; the inner largest, conical and pointed, slightly recurved and depressible; the center smaller with some larger depressible teeth and a greater number of smaller fixed teeth. A patch of depressible teeth of various sizes on the vomer, the series continuous across roof of mouth anteriorly. Two rows of conical teeth on each palatine, the inner teeth longer and more easily depressible than the outer. (The palatine teeth in larger comparative specimens of *A. filamentosus* from Madeira are in a broad band, those on a fish of intermediate size from the Azores are intermediate between a band and two parallel rows. These rows probably fuse to form a band with growth.)

Gill rakers present on first and second arches. Those on first arch bear spines along the inner side and at the tip; those on the second are covered with spines throughout, and on the third and fourth arches patches of spines on the arches themselves replace the gill rakers. Those on the first arch are of moderate length; that at the angle of the arch is about the same length as the opposing gill filament.

Distance from snout to insertion of pectoral fin 3.4 in standard length, the fin short, extending to beneath the base of the seventh dorsal ray. The upper two pectoral rays simple, the remainder branched. Distance from snout to origin of ventral fin 2.9 in standard length and about equal to predorsal length. Ventral fin long, 1.1 in length of head, extending beyond anus. The first and last rays are simple, the rest branched. The ends of the anterior four rays are thickened. Snout to origin of dorsal fin 2.8 in standard length, the fin long and high. (The anterior rays, which are filamentous in male *A. filamentosus* but not greatly produced in *A. cadenati*, may be broken in this specimen.) Length of penultimate dorsal ray 1.2 in length of base of dorsal. Anterior two dorsal rays simple. Adipose fin inserted over sixth anal ray, its length equal to width of base of ventral fin. Snout to origin of anal fin 1.5 in standard length; length of base of anal fin 2.2 in length of head. Height of fin (insertion to tip, fin depressed) almost equal to length of head. Length of penultimate anal ray much greater than depth of body at origin of anal fin, 1.8 in length of head. Distance from end of base of dorsal fin to origin of anal fin 5.3 in standard length. Anus to insertion of anal fin 2.8 in length of head.

Color in alcohol: Head purple, body yellowish with purple blotches of irregular size and not bilaterally symmetrical. Pectoral and anal fins colorless. Ventral fins, especially the thickened tips of the anterior rays, reddish. Tips of anterior four dorsal rays black, the rest of the fin dusky. Caudal fin dusky with a darker spot on the middle of each lobe.

NOMENCLATORIAL NOTE ON AULOPUS FILAMENTOSUS

Under the name of "der Borstenlachs," Bloch (1792: 424, pl. 9) described and illustrated a fish specimen from Livorno, Italy. No scientific name

was given for this species, which he recognized as new. C. S. Rafinesque-Schmaltz (1810: 56) described but did not figure a new Mediterranean species, *Salmo tirus*. This fish, probably identical with Bloch's "Borstenlachs", has been considered a synonym of *Aulopus filamentosus* since that name combination was first proposed in 1816.

This name combination appeared twice in the French dictionaries of 1816. Both entries were based on a Cuvier manuscript. Bosc (1816: 78) proposed *Aulopus* as a subgenus of *Salmo*; his entry was not accompanied by a diagnosis or description. Cloquet (1816, suppl. p. 128) accorded *Aulopus* full generic status and published a short diagnosis of *A. filamentosus*. Cuvier's description followed a year later (1817: 170).

It now seems likely that there are several species of *Aulopus* in the eastern Atlantic. In the absence of adequate series of eastern Atlantic and Mediterranean specimens, it is impossible to determine whether or not Rafinesque's poorly described *Salmo tirus* is identical with the *Aulopus filamentosus* of Cuvier or the "Borstenlachs" of Bloch. *Aulopus filamentosus* is used here for the eastern Atlantic form typified by Cuvier's description and Bloch's figure in preference to Rafinesque's earlier but at present dubious species. The trivial name should be credited to Bosc or Cloquet, not to Bloch (a common practice) or to Cuvier (prevalent in the Italian literature).

LITERATURE CITED

BLOCH, MARCUS ELIESER. *Beschreibung zweier neuen Fische*. Schrift. Ges. nat. Freunde Berlin **10:** 422–424, tab. 9. 1792.

BOSC, L. A. G. Aulopus filamentosus, in *Nouveau dictionnaire d'hist. nat., appl. aux arts, à l'agric. . . .* **3:** 78. Paris, 1816.

CLOQUET, H. Aulopus filamentosus, in *Dictionnaire des scien. nat. . . .* **3:** suppl., p. 128. Paris and Strasbourg, 1816.

CUVIER, G. L. C. F. D. *Le règne animal . . .* ed. 1, **2:** 528 pp. Paris, 1817.

——— and VALENCIENNES, ACHILLE. *Histoire naturelle des poissons* **22:** 532 pp. (roy. ed., 395 pp.). Paris, 1849.

GÜNTHER, ALBERT. *Report on the shore fishes*. Rep. Sci. Res. *Challenger . . .*, Zool. **1** (6): 82 pp., 32 pls. 1880.

POLL, MAX. *Poissons. III Téléostéens Malacoptérygiens*. Expéd. Océanogr. Belge . . . (1948–1949), Res. Sci. **4**(2): 258 pp., 8 pls. 1953.

RAFINESQUE-SCHMALTZ, C. S. *Caratteri di alcuni nuovi generi . . . Sicilia*, 105 pp., 20 pls. Palermo, 1810.

RICHARDSON, JOHN. *Icones piscium*, 8 pp., 5 pls. London, 1843.

RISSO, ANTOINE. *Histoire naturelle des principales productions de l'Europe meridionale . . .* **3:** 480 pp., 16 pls. Paris and Strasbourg, 1826.

TANAKA, SHIGEHO. *Figures and descriptions of the fishes of Japan . . .* **19:** 319–342, pls. 91–95. 1915.

VALENCIENNES, ACHILLE. *Ichthyologie des îles Canaries . . .* in Webb, P. B., and Berthelot, S., *Histoire naturelle des îles Canaries* **2**(2): 109 pp., 25 pls. Paris, 1836–44.

The most beautiful thing we can experience is the mysterious. It is the source of all true science and art.—EINSTEIN.

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ICHTHYOLOGY. *-Three new species of archibenthic iniomous fishes from th western North Atlantic.*

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(Received October 13, 1958)

The species discussed below are represented by specimens caught in moderately deep water by the United States Fish and Wildlife Service vessels *Oregon* and *Silver Bay*, the Harvard-Havana Expedition of the *Atlantis*, and by several small older collections in the United States National Museum, the Chicago Natural History Museum, and the Museum of Comparative Zoology, Harvard University.

I wish here to express my appreciation to those who, by supplying specimens for study and information about others, have contributed to this account: Dr. N. B. Marshall (British Museum); Loren P. Woods and Mrs. Marion Grey (Chicago Natural History Museum); William C. Schroeder and Mrs. Myvanwy M. Dick (Museum of Comparative Zoology, Harvard University); and Dr. Charles R. Robins (Marine Laboratory, University of Miami). My thanks also go to the scientific staff and crew of the M/V *Oregon*, particularly to Harvey R. Bullis, Jr., and Warren F. Rathjen of the United States Fish and Wildlife Service, for their hospitality and assistance while at sea and for their continued interest in the progress of work later based on the collections obtained by their vessels.

Chlorophthalmus brasiliensis, n. sp.
Figs. 1, 2

The description which follows is based on specimens collected by the U. S. Fish and Wildlife Service vessel *Oregon* during its exploration of the coastal shelf of northeastern South America (cruise 47; November 1957). This cruise made several deep-water stations between Venezuela and the Equator, and fortunately these contained representatives of the more northern *Chlorophthalmus agassizi* as well as large series of the form described below as new. Since I plan to review the infraspecific variability in western North Atlantic *C. agassizi* in a later paper, I will restrict my remarks here to a comparison of the new species, from off Northern Brazil, with the geographically adjacent population of *C. agassizi*. Except for the long-nosed greeneye, *Parasudis truculentus*, no other species of chlorophthalmid is known from the western North Atlantic.

Holotype.—A specimen 117.0 mm in standard length from *Oregon* station 2082 (see data in table): U.S.N.M. no. 156892.

Paratypes.—371 specimens from the following *Oregon* stations; all off northern Brazil.

2080 02°04′N.lat. 47°00′W.long. 125 fms. Nov. 17, 1957
2081 01°52′N.lat. 46°54′W.long. 175 fms. Nov. 17, 1957
2082 01°51′N.lat. 46°50′W.long. 200 fms. Nov. 17, 1957
2083 01°49′N.lat. 46°48′W.long. 225 fms. Nov. 17, 1957
2084 01°45′N.lat. 46°46′W.long. 275 fms. Nov. 18, 1957

TABLE 1.—FREQUENCY DISTRIBUTION OF NUMBER OF ANAL FIN RAYS, GILL RAKERS, AND PREDORSAL SCALES IN SAMPLES OF *Chlorophthalmus brasiliensis* FROM OFF BRAZIL AND OF *C. agassizi* FROM SIMILAR DEPTHS OFF VENEZUELA AND THE GUIANAS.

Anal fin rays

	7	8	9	10
C. brasiliensis (Brazil)		9	40	1
C. agassizi (Surinam)		4		
C. agassizi (British Guiana)	3	11		
C. agassizi (Venezuela)	1	12		

Gill rakers

	Upper limb			Lower limb				Total					
	2	3	4	19	20	21	22	23	22	23	24	25	26
C. brasiliensis (Brazil)		41	9		7	28	12	3		7	25	12	5
C. agassizi (Surinam)	2	2		2	2				4				
C. agassizi (British Guiana)	1	13		3	9	2			4	8	2		
C. agassizi (Venezuela)		13		6	3	4			6	3	4		

Predorsal scales

	11	12	13	14	15
C. brasiliensis (Brazil)		6	26	14	4
C. agassizi (Surinam)	1	2	1		
C. agassizi (British Guiana)	3	10	1		
C agassizi (Venezuela)	3	10			

Most of these specimens have been deposited the U. S. National Museum (U.S.N.M. nos. 59358 to 159362). Others are in the collections of the Chicago Natural History Museum; Museum of Comparative Zoology, Harvard niversity; Academy of Natural Sciences of hiladelphia; Natural History Museum, Stanord University; University of Miami Marine aboratory; British Museum (Natural Hisory); Rijksmuseum van Natuurlijke Historie, eiden; and the Stichting Surinaams Museum, aramaraibo.

Diagnosis.—The terete form, circular eye of oderate size, and prolonged tip of lower jaw ill distinguish *C. brasiliensis* from *C. agassizi*, ie highly variable species to which I refer not nly all western North Atlantic specimens which have seen (including *C. chalybeius* Goode) ut also the tropical west African *C. atlanticus* oll. *C. agassizi* is composed of several allopatric ifraspecific populations, and it will be most seful here to compare it to the population eographically nearest to it. A summary of the ost apparent characters by which the two orms can be distinguished follows:

Chlorophthalmus agasizzi, FROM OFF VENEZUELA AND THE GUIANAS	*Chlorophthalmus brasiliensis*, FROM OFF NORTHERN BRAZIL
1. Diameter of orbit greater han 40 percent of prepectoral ength.	1. Diameter of orbit less than 40 percent of prepectoral length.
2. Length of snout, in per-ent of prepectoral length, less han (23.37 + 0.189 times pre-ectoral length).	2. Length of snout, in percent of prepectoral length, greater than (23.37 + 0.189 times prepectoral length).
3. Postorbital width of ead, in percent of prepectoral ength, greater than (43.7 + .184 times prepectoral length).	3. Postorbital width of head, in percent of prepectoral length, less than (43.7 + 0.184 times prepectoral length).
4. Length of pectoral fin, in ercent of standard length, reater than (24.2 + 0.009 times tandard length).	4. Length of pectoral fin, in percent of standard length, less than (24.2 + 0.009 times standard length).
5. Anal fin rays modally 8½.	5. Anal fin rays modally 9.
6. Total number of gill akers (both limbs) modally 23.	6. Total number of gill rakers (both limbs) modally 24.
7. Number of predorsal cales modally 12.	7. Number of predorsal scales modally 13.

Description.—The proportional measurements which follow are expressed in percent of standard length and are those of the type, 117.0 mm in standard length, followed, in parentheses, by the range of values found in a series of 20 paratypes, 93.7 to 132.0 mm in length:

Length of head, 30.1 (28.7–31.4); width of head, measured between the posterior midpoints of the orbits, 14.1 (13.5–14.6); width of head, measured between the anterior midpoints of the orbits, 10.8 (10.1–11.5). Width of body, measured immediately behind the bases of the pectoral fins, 12.9 (11.5–13.5). Depth of body, at origin of dorsal fin, 16.0 (14.2–16.0); at origin of anal fin, 10.9 (10.0–12.2); at origin of adipose fin, 10.0 (8.4–10.6); least depth of caudal peduncle, 7.0 (6.6–7.6).

Length of snout, 9.4 (9.0–10.0); length of upper jaw, 13.1 (12.3–13.7); distance from snout to tip of lower jaw (mouth closed), 2.5 (2.2–2.6). Horizontal diameter of orbit, 10.9 (10.1–11.4); width of bony interorbital, 2.7 (2.7–3.1).

Distance from snout to origin of dorsal fin, 36.2 (35.4–37.8); preanal distance, 75.7 (74.5–81.3); prepectoral length, 29.2 (28.1–31.5); preventral distance, 40.8 (39.6–42.6). Length of base of dorsal fin, 10.7 (10.3–12.2); of anal fin, 7.3 (6.6–8.0). Length of pectoral fin, 22.8 (22.0–24.7); of ventral fin, 17.9 (17.6–20.0). Depressed height of dorsal fin, 20.1 (19.7–23.2); of anal fin, 13.6 (13.5–15.7). Length of upper lobe of caudal fin, measured from the base of the first upper procurrent caudal ray, —— (23.5–26.6).

D.—11. A.—9 (occasionally 8 or 10). P.—16–17. V.—9. C.—I-17-I. Gill rakers (lower limb of anterior arch)—20–23 (usually 21); total gill raker count (first arch)—23–26 (modally 24). Scales in horizontal series (between the upper point of the gill opening and the base of the midcaudal ray)—51–56. Scales between anus and origin of anal fin—18–21; predorsal scales—13–14; scale rows between origin of dorsal fin and lateral line—7–8.

Body terete, nearly circular in cross-section anteriorly but becoming compressed posteriorly. Depth of body, at dorsal origin, 1.9–2.2 in length of head. Width of body, immediately behind insertion of pectoral fin, 2.3–2.8 in length of head. Length of head 3.2–3.5 in standard length.

Body and suborbital region of head covered with imbricate, weakly denticulated cycloid scales most of which are usually lost during capture. Lateral line scales pierced by a tube but otherwise similar to body scales. No prominent axillary scales; those surrounding pelvic base and those in and below the axil of the pectoral fin somewhat larger than body scales and variously shaped.

Head broadest immediately behind eye; sides of head converging evenly forward to the

rounded snout. Tip of snout on a horizontal with center of eye and with tip of lower jaw, when the mouth is closed. Length of snout 1.1–1.2 in diameter of orbit. Lower jaw terminal, ending in a horizontal triangular plate. This mandibular extension (snout to tip of lower jaw with mouth closed) 3.5–4.2 in length of snout. Angle of gape just before a vertical from anterior edge of orbit. Maxillary ending below anterior edge of pupil. Posterior two-thirds of maxillary surmounted by a long and slender supramaxillary. Maxillary broad posteriorly, its rear edge convex and sloping downward, forward and inward.

Head covered by an extensive network of sensory pores which cannot be described satisfactorily because of the loss of skin which has occurred in almost all specimens. This system is most highly developed on the interorbital region. Particularly evident are the pores which extend onto the dermal dorsal eyelid, the circumorbital system, and the scattered series of pores on the ventral surface of the head.

Teeth present on premaxillary, dentary, palatine and vomer. Tongue, the tip of which is free, is edentulous. The terminal part of the lower jaw, which extends beyond the upper, bears a pair of toothed patches lateral to the edentulous median symphyseal ridge. These teeth are small, bristlelike and depressible. These patches are not continuous with the principal series of mandibular teeth. The extreme tip of the lower jaw, distal to the symphyseal ridge with its adjacent tooth patches, bears no teeth and is pierced by a pair of pores, the entrances to a bony tube leading to the lower surface of the mandible near its tip. These channels continue posteriorly, median to the lower edge of the rami of th mandible, passing through at least two pai of ossified tunnels. Because of skin loss, it is im possible to determine whether or not th channel, after it emerges from the bone, is completely enclosed tube; there are no rem nants of such a tube between the ossified tunnels The principal mandibular teeth are minute, de pressible, needlelike and recurved, and form band which decreases in width posteriorly.

The premaxillary teeth are minute, of abou equal size, slightly recurved and depressible, an form a narrow band. Anteriorly this band i on the ventral surface of the premaxillary; pos teriorly it is on the lateral face. The two latera knobs of the vomer bear patches of stronge teeth, most of which are depressible. Thoug widely separated, these patches are continuou with one another, in most specimens, by way of a single row of minute teeth along the an terior edge of the vomer. The palatine teeth are very small and are restricted to a band along the anterior half of that bone.

The gill rakers on the first arch are flattened and of moderate length, that of the longest about equal to the diameter of the eye lens, and longer than the gill filaments opposing it. Rakers on second arch similar but much shorter; those on the last two reduced to spine-bearing knobs.

Predorsal distance 2.6–2.8 in standard length; preanal 1.2–1.4 in length; prepectoral 3.2–3.6 in length; preventral 2.3–2.5 in length. First three dorsal rays unbranched, the third longest; the depressed height of the fin 1.3–1.5 in length of head. First three anal rays unbranched, the third longest; the depressed height of anal fin

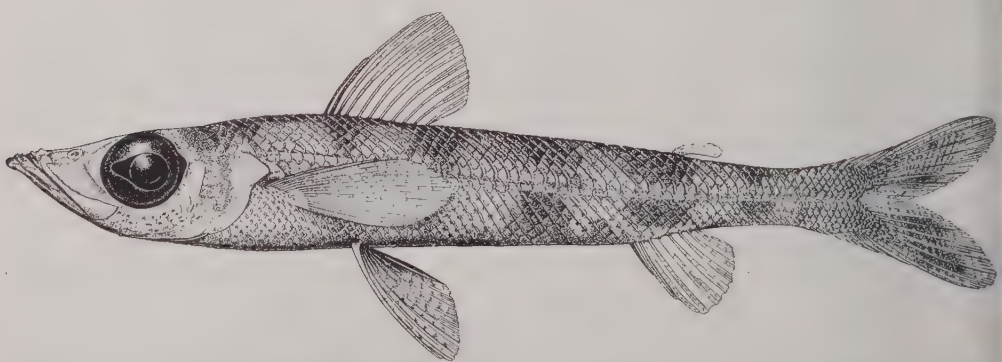

FIG. 1.—*Chlorophalmus brasiliensis*, holotype, 113.0 mm in standard length, U.S.N.M. no. 156892. (Drawn by Margaret G. Bradbury.)

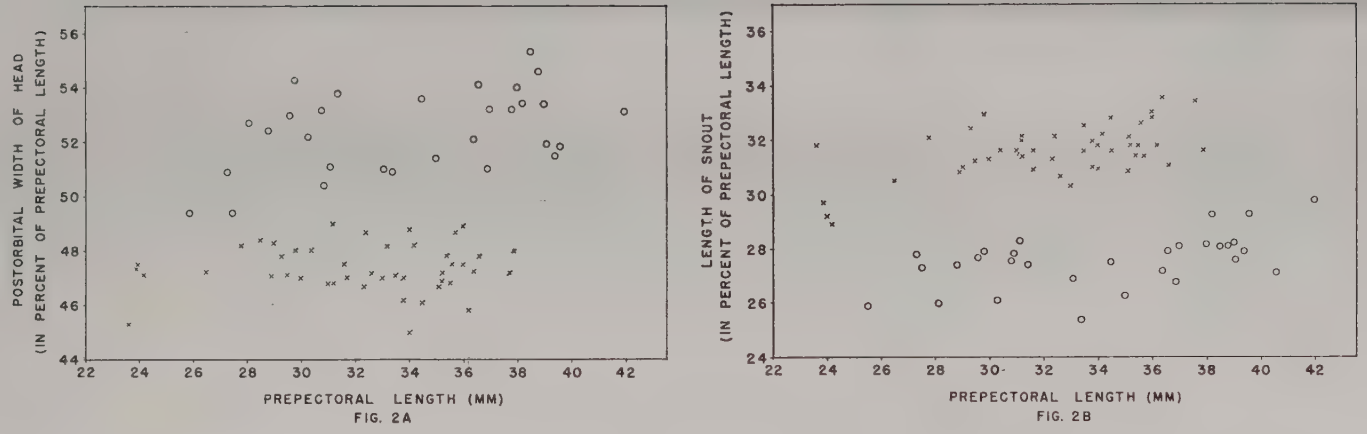

FIG. 2.– Morphometric comparison between *Chlorophthalmus brasiliensis* (X) and specimens of *C. agassizi* (0) from Venezuela, British Guiana, and Surinam: *a*, Ratio-on-size plot of postoribtal width of head, in percent of prepectoral length, against prepectoral length; *b*, ratio-on-size plot of snout length, in percent of prepectoral length, against prepectoral length; *c*, ratio-on-size plot of horizontal diameter of orbit, in percent of prepectoral length, against prepectoral length; *d*, ration-on-size plot of length of pectoral fin, in percent of standard length, against standard length.

2.0–2.2 in length of head. Length of pectoral fin 4.0–4.5 in body length; length of ventral fin 5.0–5.7 in length. Except for the bases of the caudal rays, all fins are scaleless.

Coloration.—In preservative, the background color of the body is yellowish or occasionally orange; it is nearly white ventrally, becoming brownish dorsally in fresh specimens. The irregular dark blotches below the midline are more prominent in young specimens. Broad vertical bands of variable width dorsally. Viewed from above, the most prominent of these are at the nape, each end of the dorsal fin base, midway between dorsal and adipose fins, just ahead of the adipose fin, midway between adipose fin and procurrent caudal rays, and through these procurrents. Narrower bands lie between these. The pattern, rather variable, fades with preservation in alcohol.

Tip of lower jaw and edge of upper jaw, operculum, linings of pharyngeal and abdominal cavities, eye and anus black. Snout and top of head dusky, suborbital and to a lesser extent ventral surface of head and body punctate.

A black stripe courses along the entire middorsal line, but is most conspicuous between the nape and the origin of the dorsal fin. The scale rows are delineated by black lines. Fins dusky.

Bathypterois (Bathypterois) bigelowi, n. sp.
Fig. 3

Bathypterois longipes (non-Günther), part, Goode and Bean, 1895: 66 (the juvenile recorded from *Blake* st. CXCI).

Bathypterois quadrifilis (non-Günther), Longley and Hildebrand, 1941: 25.

Bathypterois (*Bathypterois*) *bigelowi* is represented in the collections of the Chicago Natural History Museum; University of Miami Marine Laboratory; the Museum of Comparative Zoology; and the United States National Museum. Although juveniles of this species have been present in the National Museum collection since the early exploratory activity of the Fish Commission steamer *Albatross*, the identity of these has not hitherto been appreciated and they have been variously referred to *Bathypterois longipes* and *B. quadrifilis*, species to which they bear a close but superficial resemblance. More recently, the western Caribbean exploration of the U. S. Fish and Wildlife Service vessel *Oregon* (September, 1957) obtained large series of the new form, and it is now apparent that this species is the commonest bathypteroid in the western Atlantic and one which prefers waters much shallower than most of its congeners (260 to 400 fathoms).

Holotype.—A specimen 124.5 mm in standard length from the Caribbean Sea off Nicaragua, *Oregon* station 1915 (see data below); C.N.H.M. no. 64435.

Paratypes.—The following western North Atlantic specimens: 1 specimen, 90.6 mm (no precise data, western Carribean), Chicago Natural History Museum no. 64422; 10, 88.0–117.0 mm, *Oregon* station 1906 (12° 19′ N., 82° 27′ W.; 325 fms.; Sept. 11, 1957), University of Miami Marine Laboratory no. 1998 and C.N.H.M. no. 64424; 4, 65.4–106.0 mm., *Oregon* station 1908 (12° 33′ N., 82° 20′ W.; 350 fms.; Sept. 11, 1957), C.N.H.M. no. 64426; 9, 80.3–120.5 mm, *Oregan* station 1909 (12° 35′ N., 82° 19′ W.; 350 fms.; Sept. 11, 1957), C.N.H.M. no. 64427; 1, 73.0 mm, *Oregon* station 1910 (12° 40′ N., 82° 18′ W.; 350 fms., Sept. 11, 1957), C.N.H.M. no. 64428; 1, 74.6 mm, *Oregon* station 1911 (12° 44′ N., 82° 14′ W.; 350 fms.; Sept. 11, 1957), C.N.H.M. no. 64429; 3, 119.0–123.6 mm, *Oregon* station 1912 (12° 49′ N., 82° 15′ W.; 325 fms.; Sept. 12, 1957), C.N.H.M. no. 64430; 1, 98.5 mm, *Oregon* station 1913 (12° 54′ N., 82° 15′ W.; 300 fms.; Sept. 12, 1957), C.N.H.M. no. 64431; 2, 98.8–123.0 mm, *Oregon* station 1914 (13° 06′ N., 82° 13′ W.; 350 fms.; Sept. 12, 1958), C.N.H.M. no. 64432; 15 (in addition to the holotype), 76.5–129.5 mm, *Oregon* station 1915 (13° 13′ N., 82° 13′ W.; 350 fms.; Sept. 12, 1957), C.N.H.M. no. 64459 and U.M.M.L. no. 1999 (1 sp.); 5, 105.1–126.6 mm, *Oregon* station 1917 (13° 20′ N., 82° 02′ W.; 325 fms.; Sept. 12, 1957), C.N.H.M. nos. 64436 and 64437; 6, 79.4–131.0 mm, *Oregon* station 1952 (16° 46′ N., 82° 16′ W.; 300 fms.; Sept. 17, 1957), U.M.M.L. no. 2335.

Seven additional specimens are available, all in very poor condition but undoubtedly referable to this species: 4, 45.0–71.5 mm, from south of Tortugas, Fla. (Longley; U.S.N.M. no. 117214 and C.N.H.M. no. 42784); 1, 81.5 mm, Johnson-Smithsonian Expedition, *Caroline* station 1.T.T.13, off the Virgin Islands (18° 33′ 45″ N., 65° 15′ W.; 300–400 fms.; Jan. 30, 1933), U.S.N.M. no. 108292; 1, 137.6 mm, Johnson-Smithsonian Expedition, *Caroline* station 23

Fig. 3.—*Bathypterois bigelowi*, holotype, 124 mm in standard length, from the Caribbean Sea off Nicaragua; C.N.H.M. no. 64435. (Drawn by Mildred H. Carrington.)

T.113, off Puerto Rico (18° 32′ N., 66° 21′ 45″ .; 260 fms; Feb. 4, 1933), U.S.N.M. no. 8261; 1, 49.2 mm, *Blake* station 191 (25° 33′ ., 84° 35′ W.), U.S.N.M. no. 47619, and 1, .0 mm long, which was caught at *Blake* sta- *n* 154, off Monserat at 298 fms. (MCZ 926).

Recently, the *Silver Bay* caught a single venile, 75.0 mm in standard length, in the tlantic off central Florida at station 454 (29° ′ N., 79° 58′ W.; 330 fms.; June 12, 1958). he principal characters of this fish fit the escription of *B.* (*B.*) *bigelowi*, but in certain orphometric features, for example the relative ngth of head, this single specimen differs sig- ficantly. Since it was caught off the east coast Florida while most *B.* (*B.*) *bigelowi* came om the Gulf of Mexico and Caribbean, it is cluded from the account given below. More tlantic material is needed before a satisfactory mparison can be provided. This juvenile is ow in the U. S. National Museum (no. 6951).

Diagnosis.—Body light in color (possibly eenish in life), darker dorsally than ventrally. ost of dorsal fin membrane black. Membrane etween central caudal rays black. A prominent ack spot at base of upper and lower caudal bes. Membrane connecting lower rays of upper ectoral fin black.

Upper pectoral, outer ventral and lower udal rays prolonged, the tips of the produced ntral and caudal rays typically thickened. pper pectoral rays split at a point beyond igin of adipose fin. Eight ventral fin rays. econd or third anal ray considerably longer than first or fourth. Usually three rays in upper pectoral fin below the uppermost two fused and prolonged rays (frequently four lower rays in upper pectoral fin in juveniles; occasionally two in adults). These lower rays well developed and connected by a black fin membrane. Usually 9 (8 to 10) rays in lower part of the pectoral fin, none notably stronger than the others. Dorsal fin situated over or behind a vertical from axil of ventral fin; anal origin well behind end of base of dorsal fin.

Lateral line scales 48 to 55, the lateral line continuing onto the caudal fin above central caudal ray. Scales behind lower part of pectoral fin base not pectinate. Total number of gill rakers on first arch 40 or fewer. Eye minute, its greatest measure much less than the width of the posterior end of the maxillary.

No notch below caudal peduncle (*cf. B. phenax*, the notch formed by the most posterior ventral procurrent caudal ray). Vertebrae 49 to 52.

Description.—The description which follows is based primarily on the type and ten additional specimens from various localities in the western Caribbean. Fin ray counts include all specimens. In the paragraph which follows, the proportional measurements taken from the type are followed, in parentheses, by the range of measurements found in ten paratypes. All are expressed in percent of standard length.

Length of head, 24.6 (20.9–24.1); length of snout, 8.3 (7.6–8.6); length of premaxillary, 15.6 (13.4–15.4). Horizontal diameter of eye, 1.4 (1.3–1.7); interorbital width, 8.5 (7.3–8.5).

Greatest depth of body, 15.5 (12.9–15.8);

depth at origin of anal fin, 13.7 (12.1–14.4); least depth of caudal peduncle, 8.3 (7.7–9.0). Greatest width of body, 8.8 (6.7–8.9).

Predorsal distance, 43.7 (40.0–45.0); preanal, 62.6 (57.6–62.0); prepectoral, 19.7 (17.8–21.8); preventral, 42.2 (37.3–42.1). Length of base of dorsal fin, 13.3 (11.5–13.2); of anal fin, 7.6 (6.4–8.3). Distance from base of last dorsal ray to adipose fin, 22.3 (21.6–23.9); from base of last anal ray to ventral procurrent caudal ray, 30.7 (30.0–34.7). Length of produced caudal ray, 28.5 (22.7–27.7); of longest pectoral ray, 96.6 (78.1–98.3); of longest ventral fin ray, 36.7 (29.1–37.2).

D.—12–13 (13 in 35 specimens, 12 in 17, 11 in 1). A.—9 (8 in 3, 9 in 44, 10 in 6). Lower rays in upper pectoral fin—3 (both fins of each specimen counted when possible: 2 in 9, 3 in 92, 4 in 5). Lower pectoral fin—9 (8 in 5, 9 in 74, 10 in 22). V.—8 (invariable). C.—I-16-II (invariable). B. R.—11 (infrequently 10 or 12). G. R.—10–12 + 1 + 22–28 = 33–40. Scales in lateral line—48–55. Vertebrae—(in 14 specimens from *Oregon* station 1915, western Caribbean),—49–52 (51 in 8 of these specimens).

Body compressed, snout depressed. Body deepest at origin of dorsal fin, 1.5 to 1.8 in length of head; depth at origin of anal fin 1.6 to 2.0 in head; least depth of caudal peduncle 2.5 to 3.1 in head.

Cheeks and body scaled; all scales cycloid. Lateral line complete, originating at upper point of gill opening and terminating on caudal fin above central caudal rays. Base of caudal fin scaled, all other fins naked.

Head 4.1 to 4.9 in standard length, nearly flat dorsally, rounded anteriorly but with a slight indentation at tip to receive symphyseal knob of lower jaw. Length of snout 2.8 to 3.3 in head. Top of head pierced by nostrils and a pair of longitudinal series of pores. Olfactory organ well developed, nostrils separated by a membrane which bears a short flap.

Eye small, horizontally eliptical and laterally directed, much smaller than greatest width of maxillary, 3.8 to 6.0 in length of snout. Eye relatively larger in juveniles. A horizontal row of about four pores below eye. Interorbital 2.7 to 3.0 in head length.

Branchiostegal membranes broad and free from isthmus, extending beyond rear edge of operculum but not reaching insertion of lower pectoral fin. Four branchiostegal rays on epihyal; seven on ceratohyal. Opercular bones well developed and firm.

Gill rakers present on all four arches, spinulose, flattened; those near angle of first arch about twice the length of the opposing gill filaments.

Length of maxillary 1.6 to 1.8 in head, surmounted by a thin long supramaxillary which terminates anteriorly under rear edge of eye. Premaxillaries slender and separate from one another. Mandible heavy, its outer lower surface pierced by pores. A small edentulous symphyseal knob present. A band of minute teeth on premaxillary and mandible, both broader anteriorly. A small patch of minute teeth frequently but not always present on vomer, and an occasional row of very small teeth on palatine. Tongue toothless. Well developed patches of pharyngeal teeth.

Dorsal fin inserted well behind bases of inner ventral rays; predorsal distance 2.2 to 2.5 in standard length. First two dorsal rays simple, the rest branched. Adipose dorsal well-developed and broad, placed about equidistant from end of dorsal base and base of upper procurrent caudal rays. Anal inserted well behind a vertical from last dorsal ray; preanal distance 1.6 to 1.7 in body length. The first and occasionally the second anal ray simple, the second or third longer than its neighbors, markedly longer in most specimens than those in most bathypteroid species.

Lower two principal caudal rays simple and produced, their ends frequently slightly thickened. Lower branch of the branched ray immediately above the simple rays also elongated. The segments which form the lower simple rays and this lower branch of the first divided ray are much shorter than those of the caudal rays above them. These segments become shorter distally.

Two outer ventral fin rays simple and produced, extending beyond base of anal fin in adult. Distance between snout and insertion of ventral fin 2.4 to 2.7 in standard length. Upper two rays of pectoral fin united basally, separate distally, the split posterior to origin of adipose fin. Lower rays of upper pectoral fin well developed and connected by a black fin membrane. Usually four such rays in the juvenile but typically three in the adult. Lower pectoral rays (typically 9) well developed and stiffened, arching slightly upward, the longer extending

beyond end of base of dorsal fin. Lower pectoral rays about equal to one another in strength basally, Prepectoral distance 4.6 to 5.6 in standard length.

Coloration.—Living specimens are probably greenish in general body color. The background color of specimens preserved in alcohol is white, stippled below the midline by small black spots and darkened above by diffuse dark pigmentation in each scale pocket; the margin of each scale pocket is pigmentless. Head and ventral surface of body anterior to ventral fin darker. Mouth, branchiostegal membrane, and pharyngeal and abdominal cavities black. Lower pectoral fin and ventral fins colorless. Membranes connecting lower rays of upper part of pectoral fin, dorsal rays, and midcaudal rays black. A large conspicuous black spot at base of upper and lower caudal lobes.

Relationships.—*Bathypterois bigelowi* is unquestionably most closely related to *B. longifilis* Günther, a species which the *Challenger* dredged at 520 and 630 fathoms off the Kermadec Islands in the South Pacific. Both of these specimens were large females, about 13 inches long, and the species has not since been reported. *B. bigelowi* can be distinguished from Günther's species by the strong black pigment in the membrane which connects the lower rays of the upper part of the pectoral fin (colorless in *longifilis*), 9 or 10 rays in the lower pectoral fin (*cf.* 13), the greater length of the second anal ray, the total gill raker count (33–40 *cf.* 42), the presence of the large, conspicuous spots at the base of the caudal lobes and the general body coloration, and the more elongate outer ventral and lower caudal rays.

Bathypterois (*Bathypterois*) *bigelowi* cannot easily be confused with any other known North Atlantic bathypteroid species, a preliminary key to which follows below. In this key, *Bathypterois* (*Hemipterois*) *nigrescens* Parr is considered questionably distinct from *B.* (*H.*) *viridensis* Roule. *Bathypterois* (*Bathypterois*) *quadrifilis* has been described and figured as having no subcaudal notch (Günther, 1878: 184; Günther, 1887: 189, pl. 33; Goode and Bean, 1895: 65, fig. 75), but I have checked the Goode and Bean specimens, and Dr. N. B. Marshall has reexamined Günther's *Challenger* types; a subcaudal notch is present on all. *Bathypterois* (*Bathypterois*) *dubius* is probably polytypic.

KEY TO THE GENERA, SUBGENERA, AND NORTH ATLANTIC SPECIES OF BATHYPTEROID FISHES

a. Pectoral fin divided into two distinctly different parts, the uppermost pectoral ray usually stiffened and elongate. Outer ventral and lower caudal rays frequently prolonged but never longer than the sandard length of the fish. Adipose fin usually present (present in all known western Atlantic specimens).
genus *Bathypterois*

b. Uppermost pectoral ray not notably thicker at its base than its neighbor; all rays of upper part of pectoral well developed. Six or fewer rays in lower part of pectoral fin.
subgenus *Bathypterois* (*Hemipterois*)
B. (*H.*) *viridensis* Roule
B. (*H.*) *nigrescens* Parr

bb. Uppermost pectoral ray at least twice as thick as that of its neighbor. Lower rays of upper pectoral fin poorly developed. More than 6 rays in lower part of pectoral fin...subgenus *Bathypterois* (*Bathypterois*)

c. Scales behind base of lower part of pectoral fin strongly pectinate. Lower ray of lower pectoral fin long and strong, conspicuously heavier at its base than its neighbor. Subcaudal notch present.
B. (*B.*) *quadrifilis* Günther

cc. Scales behind base of lower pectoral fin not pectinate. Lowermost ray of lower pectoral fin not notably thicker than its neighbor.

d. Subcaudal notch present.

e. Origin of anal fin behind a vertical from end of base of dorsal fin. Eight ventral rays...*B.* (*B.*) *dubius* Vaillant

ee. Origin of anal fin under end of base of dorsal fin. Nine ventral rays.
B. (*B.*) *phenax* Parr

dd. No subcaudal notch.

f. Lower rays of upper pectoral rudimentary and not connected by a black membrane. Interradial membrane of dorsal fin colorless. Body uniformly dark. Caudal lobes dusky but without conspicuous black spots at their bases. Central caudal rays colorless...*B.* (*B.*) *longipes* Günther

ff. Lower rays of upper pectoral fin well developed, connected by a membrane which is black. Interradial membrane of dorsal fin black. Body darker above than below. A prominent black spot at bases of upper and lower caudal lobes. Membrane between central caudal rays black.
B. (*B.*) *bigelowi* Mead

aa. Pectoral fin not divided into two parts, the fin situated high on the shoulder and without greatly prolonged rays (none extend beyond anal fin). Outer ventral and lower caudal rays longer than standard length of fish. No adipose fin.
Benthosaurus grallator Goode and Bean

Bathytyphlops marionae, n. sp.

Fig. 4

It is difficult to imagine a free-living fish more degenerate than the species of the genus *Bathytyphlops*. They are undoubtedly blind, for the eyes are vestigial and covered by skin and occasionally scales; and none of the other sensory structures are notably enlarged. They lack the elongate tactile rays of the bathypteroids, and the small villiform teeth and cephalic luminous organ of *Ipnops*. The "teeth" of *Bathytyphlops* consist of broad rugose grinding surfaces on most of the jaw and pharyngeal bones. These fishes cannot be active carnivores. But neither can they be filter feeders, for the gill rakers, normal and flattened in the related species of *Ipnops* and *Bathymicrops*, are reduced to low dentigerous rudiments. Only that at the angle of the gill arch is developed, this excessively so. They may perhaps be carrion feeders, although their relatively large (180–350 mm) size suggests nutritional requirements of some magnitude, and it seems unlikely that carcasses of sufficient size to warrant the large grinding surfaces are numerous in their habitat.

The specimens described below are the first *Bathytyphlops* known from the Atlantic. The single species heretofore described, *Bathytyphlops sewelli* (Norman) was caught in the Arabian Sea at a depth of 3840 to 3872 meters (Norman, 1939: 26) and from an unspecified *Galathea* station (Bruun, 1956: 171). These western Atlantic records thus extend the range of the genus half way around the world and, more significantly, into far shallower water, for the depths of capture here were 475 and 550 fathoms (868 and 1,000 meters).

It gives me pleasure to name this new and bizarre species in honor of Mrs. Marion Grey, Chicago Natural History Museum, in recognition of her contributions to the ichthyology of the deep sea.

Holotype.—A 279.0 mm specimen caught in the Caribbean at *Oregon* station 1955 (16° 48′ N., 82° 33′ W.; 550 fathoms; Sept. 17, 1957); Chicago Natural History Museum no. 64439.

Paratype.— A specimen 263.0 mm long taken by the Harvard-Havana Expedition at *Atlantis* station 2991 (Strait of Florida north of Cuba; 23° 21′ N., 80° 23′ W.; 475 fathoms; March 14, 1938; Museum of Comparative Zoology no. 39394).

Diagnosis.—Eye present, minute but pigmented and with a well-developed lens; covered by skin but not scales. Pectoral fin 12 or 13; dorsal 12 or 13; anal 13–14. 64 or 65 scales in lateral line.

Description.—The proportional measurements which follow, expressed in percent of standard length, are those of the type, 279.0 mm, followed in parentheses by those of the 263.0 mm specimen (paratype):

Length of head, 23.1 (22.4); length of snout 7.5 (6.6); of premaxillary, 17.0 (16.6); diameter of eye (horizontal): .7 (.8); width of interorbital, 8.6 (8.5).

Greatest depth of body, 16.0 (—); depth at origin of anal fin, 10.3 (9.9); least depth of caudal peduncle, 7.7 (7.2). Greatest width of body, 9.4 (9.8).

Distance from snout to origin of dorsal fin, 39.1 (40.3); to origin of anal fin, 69.6 (69.0); to insertion of pectoral fin, 21.3 (21.7); to insertion of ventral fin, 37.5 (37.9). Length of base of dorsal fin, 12.7 (12.2); length of base of anal fin, 14.0 (12.4). Anus to insertion of ventral fin, 10.8 (—); to origin of anal fin, 22.0 (—).

Distance from insertion of ventral fin to origin of anal fin, 32.4 (33.2); from end of base of dorsal fin to that of midcaudal ray, 47.5 (48.3); from end of anal base to base of midcaudal ray, 17.6 (17.5). Depressed height of dorsal fin, 21.7 (20.1); of anal fin, 19.4 (17.2). Length of central caudal ray, 8.6 (10.4); length of pectoral, 20.1 (17.1); of ventral, 16.7 (15.4).

D.—12–13. A.—13–14. P.—12–13. V.—8. C.—I-17-I. B.R.—15–17. Scales (lateral line)—64–65; from D. to lateral line—8; from 1.1. to A.—6. Vertebrae (including hypural)—63–64.

Body moderately compressed, snout somewhat depressed. Body deepest at origin of dorsal fin, this depth about 1.4 in head length, about 6.2 in standard length. Depth at anal origin 2.2 to 2.3 in head; least depth of caudal peduncle 3.0 to 3.1 in head. Greatest width of body about 1.7 in greatest depth.

Entire top of head, cheeks, anterior part of branchiostegal membrane and gular membrane, entire body, and base of caudal rays scaled, the scales (as well as can be determined) cycloid, deciduous. (Few scales remain on the two study specimens.) A broad sheath of scales extending across venter between (and partly covering) bases of inner ventral rays. An enlarged rounded scale in axil of pectoral fin, and rows of more

longate scales along bases of dorsal and anal ns. Lateral line well developed, the scales ierced by a longitudinal tube which also opens bove and below. Lateral line begins above base f pectoral fin and ends at base of caudal; it oes not continue onto the caudal fin.

Head of moderate size, the lower jaw termial; Head 4.3 to 4.5 in standard length. Rear argin of head formed by the branchiostegal embrane, the rear border of the head (edge f gill cover) sloping obliquely downward and ackward; the most posterior point below the osterior half of the base of the pectoral fin. op of head covered by skin and scales, the ead bones well ossified, the ankyloses poorly eveloped. Olfactory organs well developed, ightly closer to tip of snout than to eye. A in tube around anterior nostril, this tube enarged into a flap posteriorly between the nosrils. Behind each posterior nostril are a pair f slits which do not communicate with the olactory cavity; the function of these is not apparent. Top of head without the ossified pores haracteristic of many related species. Eye miute, covered by skin but apparently not scaled ver. A few poorly ossified circumorbital bones oating free in skin around eye. Interorbital idth 2.6 to 2.7 in length of head.

Branchiostegal membranes broad, free from thmus and from each other, the left overapping the right. Isthmus relatively broad nd scaled. Branchiostegal membranes scaled, overed anteriorly by a thick, broad and scaled ransverse gular fold. Branchiostegal rays well eveloped, the uppermost not notably flattened. Opercular bones large and well ossified, the operculum ending posteriorly with the well-developed suboperculum.

Gill rakers on first arch consist of one large heavy raker at angle, the length of which is equal to the distance between the nostrils, and basal ossifications (about 6 on the epibranchial, 12 to 14 on the ceratobranchial) which represent rudimentary rakers. These rudiments, the edges of the branchial bones, and the enlarged raker at the angle are covered by minute short spines which provide a rugose surface similar to the tooth patches on jaws and vomer. The succeeding arches bear similar rugose patches, and the pharyngeals are completely covered with patches of similar although larger teeth.

Premaxillary long and slender, 1.3 to 1.4 in length of head. Lower and outer surface completely covered with denticles, giving the bone a rugose appearance. Maxillary slender for most of its length when viewed from the side, but expanded in the horizontal plane. Posteriorly, the maxillary is expanded vertically and surmounted by an irregularly-shaped supramaxillary. A short fleshy flap at posterior end of maxillary. No teeth at symphysis of either jaw. Palatine, pterygoid and vomerine teeth similar, the toothed patches large. The two tooth-bearing patches on vomer separated by a deep trough. Mandible broad and heavy, its outer lower surface pierced by the series of pores characteristic of many deep-water inioms. Lower edges of mandibles well separated from one another (in contrast to the situation in the bathypteroids, in which the lower edges of the dentaries very nearly meet along the mid-ventral line). Articular bone exceptionally long, extending for-

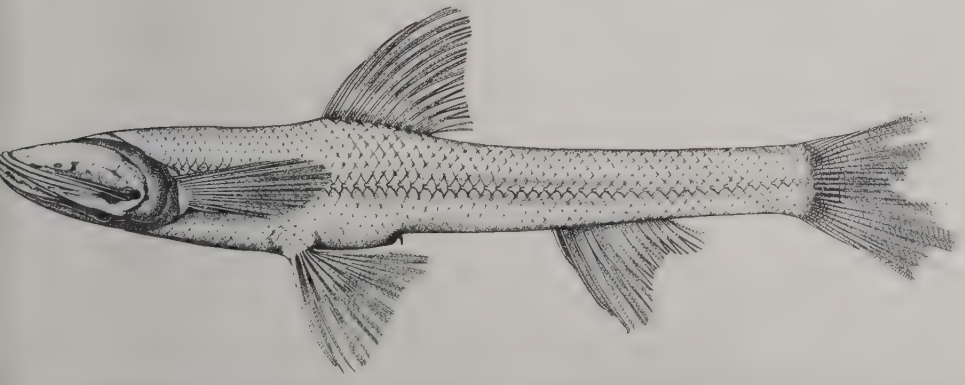

FIG. 4.—*Bakhytyphlops marionae*, holotype, 279 mm in standard length, from the Gulf of Mexico off Florida; C.N.H.M. no. 64439. (Drawn by Mildred H. Carrington.)

ward half the distance from joint of mandible to tip of lower jaw. Mandible ending anteriorly in a small knob. Symphysis without teeth, the rest of the upper surface covered with the molariform denticles characteristic of the other tooth-bearing bones of the mouth.

Dorsal fin inserted just behind a vertical from insertion of ventral; predorsal distance 2.5 to 2.6 in standard length. First two dorsal rays simple, the rest branched, the last to its base. Distance from dorsal origin to tip of fin when fin depressed 4.6 to 5.0 in standard length; length of base of dorsal fin about 1.8 in head length. Anal origin posterior, preanal distance 1.4 to 1.7 in standard length; distance between end of base of anal fin and base of midcaudal ray about 5.7 in standard length. Height of anal fin (depressed) 1.2 to 1.3 in head length. Two or three rays simple, the remainder branched. Caudal fin forked, the lobes equal.

Prepectoral distance 4.6 to 4.7 in standard length. Fin extending to base of ventral fin, its length 1.1 to 1.3 in length of head. Uppermost two and lower two rays simple. Preventral distance 2.6 to 2.7 in standard length, the outer ray only unbranched. Length of ventral fin 1.4 to 1.5 in length of head. Anus about a third of the distance from insertion of ventral fin to origin of anal.

Color.—In alcohol, *B. marionae* is light with dark edges around the scale pockets (the body may be wholly dark when the animal is alive and with its skin and scales intact). Head dark. Branchiostegal membrane, fins, and linings of body cavities black.

Relationship.—Bathytyphlops marionae is very closely related to the Indian Ocean *B. sewelli*, differing from it in some body proportions and in the features given in the diagnosis above. Dr. N. B. Marshall has generously reexamined the type specimen in my behalf, and his comments on the gill raker structure and eyes of this specimen are noted here since they were omitted from the original account provided by Norman. Dr. Marshall reports that there is an enlarged gill raker (5.5 mm) at the angle of the first gill arch, the rest of the rakers being rudimentary and the gill raker count: 6 + 1 + 11. The eye rudiment is not absent but is barely visible beneath the skin. Its diameter is about 1.5 mm, and there is a narrow pigmented ring around the opaque center. In gill raker structure, *B. sewelli* is thus similar to *B. marionae*. The vestigial eye of *B. marionae*, about 2.5 mm in diameter in the 279-mm type, is rather larger than that in Norman's 350-mm specimen.

LITERATURE CITED

Bruun, A. F. *Animal life of the deep sea bottom. In* Bruun *et al.*, ed., The Galathea Deep Sea Expedition, 296 pp., 1 chart. New York, 1956.

Goode, George Brown, and Bean, Tarleton H. *Oceanic ichthyology*. U. S. Nat. Mus. Special Bull. 2: 553 pp., 123 pls. 1895.

Günther, Albert. *Preliminary notices of deep-sea fishes collected during the voyage of the H.M.S. Challenger*. Ann. Mag. Nat. Hist., ser. 5, **2**: 179–187. 1878.

———. *Report on the deep-sea fishes* . . . Rep. Sci. Res. . . . *Challenger* . . . , Zool., **22**: 335 pp., 73 pls. 1887.

Longley, William H., and Hildebrand, Samuel F. *Systematic catalogue of the fishes of Tortugas, Florida*. Pap. Tortugas Lab. **34** (Carnegie Inst. Washington Publ. 535): 331 pp., 34 pls. 1941.

Norman, J. R. *Fishes*. Sci. Rep. *John Murray* Exp. 1933–34, **7**(1): 116 pp. 1939.

The new powers that science has given to man can only be wielded safely by those who, whether through study of history or through their own experience of life, have acquired some reverence for human feelings and some tenderness toward the emotions that give color to the daily existence of men and women.—Bertrand Russell.

STUDIES ON THE FAUNA OF SURINAME
AND OTHER GUYANAS: No. 5.

THE WESTERN ATLANTIC JAWFISHES OF THE OPISTHOGNATHID GENUS LONCHOPISTHUS

by

GILES W. MEAD

(Ichthyological Laboratory, U.S. Fish and Wildlife Service, U.S. National Museum, Washington)

During 1957 two important collections of fishes were obtained from off the coast of Suriname and adjacent regions. The first of these was made by the motor vessel "Coquette", a commercial shrimp trawler which engaged in exploratory work for the Government of Suriname. Mr. JAMES B. HIGMAN of the United States Fish and Wildlife Service was invited to accompany the "Coquette" during part of this work, and the collection of fishes which resulted was due largely to his efforts. The second collection was obtained by the motor vessel "Oregon", exploratory vessel of the United States Fish and Wildlife Service. During November, 1957, the "Oregon" occupied over a hundred trawl stations along the northern coast of South America between Venezuela and the Equator. Most of these collections are now in the U. S. National Museum and the Chicago Natural History Museum.

Both the "Oregon" and the "Coquette" collections contain representatives of a distinctive new species of *Lonchopisthus*. The definition of this species has required a review of the western Atlantic species of the genus. I take pleasure in naming this new species of *Lonchopisthus* from Suriname in honour of its collector:

Lonchopisthus higmani, new species

(Figure 41)

HOLOTYPE: 103.9 mm. in standard length. *Coquette* Station no. 216: SURINAME; 6°41′30″ N. lat., 54°16′ W. long.; June 14, 1957; 1713 to 1733 hours; 24 fathoms;

try-net (shrimp trawl); mud bottom. United States National Museum no. 158983.

PARATYPES: 82.0 mm.; *Coquette* St. 220: SURINAME; 6°42′30″ N. lat., 54°11′ W. long.; June 14, 1957; 1910 to 1930 hours; 23 fms.; try-net; mud bottom; Rijksmuseum van Natuurlijke Historie. — 86.5 mm.; *Coquette* St. 218: SURINAME; 6°42′ N. lat., 54°13′30″ W. long.; June 14, 1957; 1810 to 1830 hours; 24 fms.; try-net; mud bottom; Stanford University Natural History Museum no. 50186. — 89.0 mm.; *Coquette* St. 221: SURINAME; 6°42′30″ N. lat.; 54°10′ W. long.; June 14, 1957; 1940 to 2000 hours; 23 fms.; try-net; mud bottom; USNM 158984. — 104.0 mm.; *Oregon* St. 2017; SURINAME; 7°12′ N. lat., 54°08′ W. long.; Nov. 8, 1957; 40 fms.; 40-foot flat shrimp trawl; Chicago Natural History Museum no. 64343. — 108.5 mm.; *Coquette* St. 220: SURINAME; 6°42′30″ N. lat., 54°11′ W. long.; June 14, 1957; 1910 to 1930 hours; 23 fms.; try-net; mud bottom; Academy of Natural Sciences of Philadelphia no. 80988.

Diagnosis: A deep-bodied *Lonchopisthus* with a blunt and rounded head, a large black spot on the operculum, three or four branched caudal fin rays, fewer than 57 gill rakers on the first gill arch, and more than 40 pores in the lateral line.

Description [1]): The counts and proportional measurements of the six known specimens are recorded in Table 2.

D.: XI–17½ to XI–18½. A.: III–17½. P.: 19 or 20. V.: I–5. Vertebrae: 10+17+1. Gill rakers (first arch): 18 to 19 + 32 to 34 = 51 to 53. Pores in lateral line: 42 to 51. Scales in horizontal series below lateral line: 59 to 70.

Body compressed, its width, immediately behind insertion of pectoral fin, 7.9 to 8.2 in standard length; its greatest depth under anterior dorsal spines, 2.9 to 3.2 in length; least depth of caudal peduncle 2.9 to 3.2 in length of head. Greatest width of head 1.6 to 2.0 in length of head. Viewed from above, the body tapers from its maximum width (at preoperculum) to the highly compressed caudal peduncle.

Top of head, snout, jaws and lower half of opercles naked.

[1]) All measurements were made with dial calipers and recorded in tenths of millimetres. Total counts of the vertical fins were confirmed by use of X-ray photographs. Vertical fin counts which terminate in "½" indicate that the last ray is split to its base. These counts are considered reliable, with the exception of the count of total caudal rays. Some buried procurrent caudal rays may have been overlooked, especially those of the small comparative specimens of *L. micrognathus* and *L. lindneri* (Table 2). "Length" refers to standard length unless otherwise qualified. "Head length" refers to the distance from the tip of the snout to the most posterior limit of the opercular flap, not to the tip of the opercular spine, unless so specified.

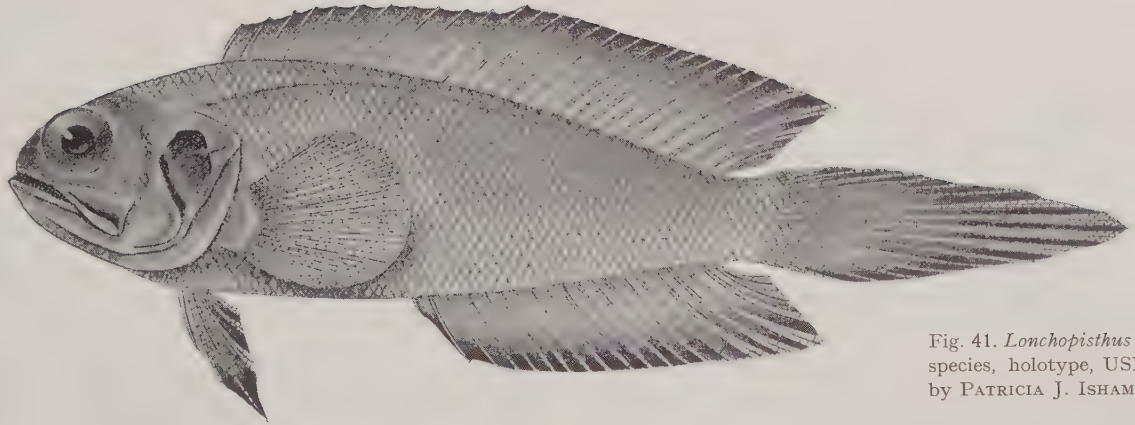

Fig. 41. *Lonchopisthus higmani* Mead, new species, holotype, USNM 158983. Drawn by Patricia J. Isham.

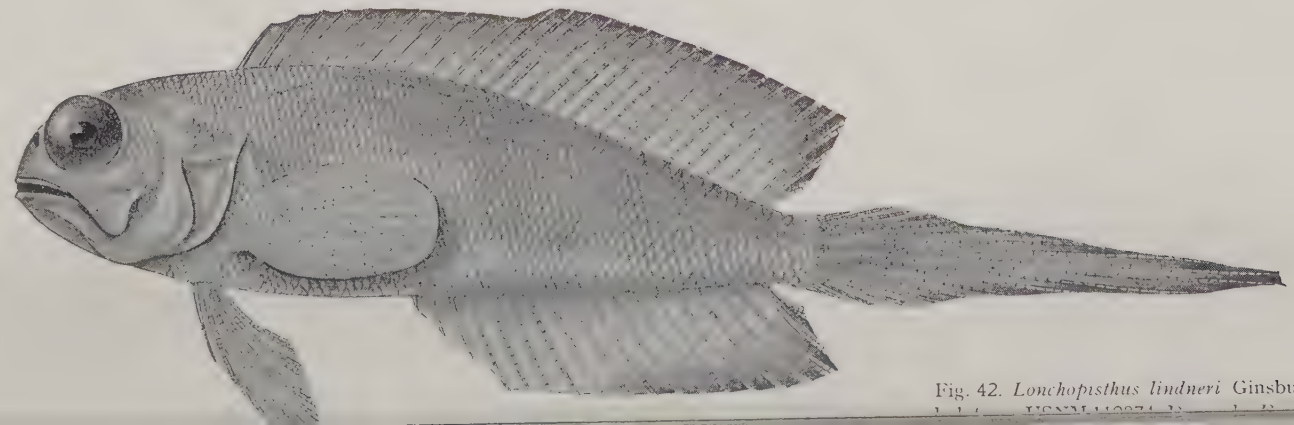

Fig. 42. *Lonchopisthus lindneri* Ginsburg,

Cheeks, body and base of caudal fin scaled. No modified axillary scales. Scales on head completely covered by skin; those on body largely covered by skin. All scales imbricate, cycloid. Lateral line begins above upper end of gill cleft, courses upward and rearward to below the fifth to seventh dorsal spine, and extends posteriorly along the back (separated from the back by one full row of scales) to its terminus below the seventh to ninth soft dorsal ray. Lateral line pores difficult to count anteriorly, 42 to 51. Scales in horizontal series 59 to 70, irregular, difficult to count anteriorly and bilaterally variable. 22 to 24 horizontal rows of scales between origin of anal fin and base of dorsal fin, counting upward and backward. 9 or 10 rows of scales between base of last anal ray and upper procurrent caudal rays. 16 to 18 rows of scales along venter between base of ventral fins and anus.

Head rounded anteriorly, gape terminal, eye large, circular, and entering into dorsal profile. Eye 2.8 to 3.2 in head; interorbital 2.2 to 2.8 in eye. Nostrils double; the anterior smaller than the posterior, below it, and with a short tube; posterior nostril situated immediately before anterior edge of orbit. Upper jaw extends beyond orbit, its length 1.6 to 1.9 in head length. Maxillary expanded posteriorly, the expanded width 1.3 to 1.7 in diameter of eye. Maxillary with a notch on its rear edge and surmounted by a broad supramaxillary. Premaxillary slender, tapering posteriorly, and slightly protractile, the anterior premaxillary process reaching level of posterior nostril.

Teeth on premaxillaries and mandible. Vomer, palatines and tongue without teeth. 14 to 25 widely spaced pectinate teeth on each premaxillary; 13 to 20 on each side of the mandible. The posterior mandibular teeth of some specimens are closely spaced.

Gill cover ending in a broadly-rounded opercular flap which is preceded by a strong but short opercular spine. This spine originates on the operculum near the top of the large black opercular spot. Six branchiostegal rays, the branchiostegal membranes separate and free from the isthmus. Gills four, each bearing flattened rakers of moderate length. Length of longest raker on first arch, near angle of arch, 1.6 to 1.9 in diameter of eye; longer than the opposing gill filament.

TABLE 2

Counts and measurements taken from specimens of *Lonchopisthus higmani* and other western North Atlantic species.

	L. higmani, holotype, SURINAME.	*L. higmani*, paratypes, 5 specimens, SURINAME.	*L. vanderbilti*, holotype, CUBA.	*L. lindneri*, holotype, USNM 119874, TEXAS.	*L. lindneri*, paratype, USNM 119878, TEXAS.	*L. lindneri*, UMML 563, TORTUGAS.	*L.* sp., CNHM 61701, CAMPECHE.	*L.* sp., CNHM 61319, western Gulf of MEXICO	*L. microgmathus*, USNM 4785, MCZ 12515 & 12517, 5 specimens CUBA.
Standard length (mm.)	103.9	82.0 108.5	68.9	60.0	62.8	60.7	50.0	88.5	59.0 80.0
Counts:									
Dorsal fin	XI–18½	XI–17½ – XI–18½	XI–19	XI–19	XI 18½	XI–18½	XI–17½	XI–17½	XI–17½ – XI–18½
Anal fin	III–17½	III–17½	III–18½	III–16½	III–16½	III–16½	III–17½	III–15½	III–16½ – III–17½
Pectoral fin	20	19-20	19	18	18/19	18	19	18	18–19
Caudal fin – total	24	23–24	–	23	–	–	–	25	–
,, ,, – segmented	16	16	16	16	–	16	16	15	15–16
,, ,, – branched	4	3–4	0	0	–	0	0	0	0
Vertebrae	10+17+1	10+17+1	10+17+1	10+17+1	10+17+1	10+17+1	10+17+1	10+17+1	10+17+1
Gill rakers	19+34	18–19+32–34	21+39	17+33	20+35	20+33	19+33	19+36	21–23+39–40
Measurements (% of standard length)									
Greatest depth of body	30.9	30.0–34.2	25.5	27.8	27.9	28.2	26.4	27.2	21.7–26.3
Least depth of caudal peduncle	10.4	9.6–10.6	6.8	9.0	8.4	8.6	8.8	8.1	7.7– 9.2
Greatest width of body, behind pectoral fin	12 2	12.1 12.6	12.5	11.7	11.9	11.9	13.0	12.9	7.6 10.5
Greatest width of head	16.4	15.2–18.8	13.6	15.5	14.0	14.5	14.8	14.8	11.0 13.6
Greatest length of head	30.6	30.6–31.7	–	29.3	29.8	30.3	30.0	28.5	25.0 27.8
Length of head (to tip of opercular spine)	28.0	27.7–30.1	24.8	27.3	28.0	26.7	27.0	25.4	24.0 25.6
Length of premaxillary	17.1	17.6–18.9	15.4	17.5	17.2	17.1	15.6	17.1	15.6–16.9
Width of posterior end of premaxillary	5.3	5.2– 7.1	5.7	6.3	5.9	5.3	4.8	5.8	4.0– 6.1
Horizontal diameter of orbit	9.3	9.1– 9.6	8.9	10.2	10.8	9.1	9.4	7.9	8.1– 9.0
Width of bony interorbital	3.7	3.3– 4.1	2.8	2.6	2.7	2.6	2.4	2.3	2.3– 2.8
Length of longest gill raker	–	4.9– 5.5	4.5	4.2	5.6	5.1	4.0	4.9	3.8– 5.2
Height of opercular spot	10.1	8.2–10.1	–	–	–	–	–	–	–
Width of opercular spot	5.8	5.3– 6.3	–	–	–	–	–	–	–
Snout to origin of dorsal fin	30.4	31.2–34.6	26.9	30.0	31.0	30.2	29.2	27.7	26.6–27.9
Snout to origin of anal fin	56.4	50.8–56 4	49.2	50.9	54.2	50.0	58.0	48.6	46.5–51.5
Snout to insertion of pectoral fin	29.4	29.4–32.4	27.9	28.3	32.0	29.6	31.6	29.4	26.4–29.1
Snout to insertion of ventral fin	26.1	26.1–29.2	25.2	25.9	27.9	25.7	–	28.3	24.3 26.2
Length of pectoral fin	23.5	20.0–24.6	19.6	22.5	24.8	21.1	22.8	20.0	19.6–21.0
Length of ventral fin	22.5	20.0 27.3	29.0	25.0	31.2	27.3	30.0	26.1	25.0–30.0

Spinous and soft dorsal fins continuous; the longest elements are the posterior soft rays which, when depressed, extend beyond the bases of the caudal fin. Last 4 to 8 dorsal and anal rays divided. Dorsal originates above posterior edge of opercular spot; predorsal distance 3.1 to 3.3 in body length. Anal origin below about the second dorsal ray; preanal distance 1.7 to 2.0 in body length. Length of anal base 2.3 to 2.4 in body length. Anal fin rays increasing in length posteriorly.

Caudal fin lanceolate, the median three or four rays branched (the fourth central caudal ray of one of the specimens with but three branched rays shows evidence of damage and subsequent repair). 16 segmented caudal rays. 23 or 24 caudal rays including the procurrent rays (from X-ray photographs). Length of caudal fin 1.9 to 2.1 in body length.

Pectoral fin inserted under posterior edge of gill flap, rounded, and extending posteriorly to a vertical with anus or beyond; its length 4.3 to 6.9 in body length, becoming relatively longer with increase in body size. Uppermost and lowermost two rays simple, the rest branched. Ventral fin inserted in advance of pectoral and composed of a spine and five variably branched rays. Preventral distance 3.4 to 3.8 in body length. Length of ventral fin 3.7 to 5.0 in body length, the third and fourth rays longest.

Colour in alcohol: background colour light brown with a little evidence of vertical cross-banding. Head, particularly the snout, darker. The membrane beneath lower part of posterior expansion of the maxillary which connects the inner surface of the maxillary to the fleshy lip lateral to the dentary is black (the "opisthognathid spot"). A large, black spot on the operculum, the vertical measure of which is greater than that of the eye. Mouth, pharynx, and peritoneum pigmentless.

Spinous dorsal fin dusky and distally black. Soft dorsal and anal fins black, the pigment becoming more intense distally and posteriorly. Caudal black. Intensity of pigmentation on pectoral fin similar to that on body. Ventral fins black.

The western Atlantic species of Lonchopisthus

There are four nominal species of this western Atlantic genus: *L. micrognathus* (Poey, 1860), Cuba; *L. vanderbilti* Mowbray, 1928 (*in* Borodin, 1928), Cuba; *L. lindneri* Ginsburg, 1942, Gulf of Mexico off Texas; and *L. higmani* from Suriname. I have had the type specimens of these and some limited additional material available for study, but the paucity of specimens and their size distribution prevents me from providing a satisfactory revision of the species. The synopsis and the remarks which follow are provisional. The named species can be separated as follows:

a. No branched caudal fin rays
  b. Fewer than 56 gill rakers on the first arch. No opercular spot . . . . . *L. lindneri*
  bb. More than 56 gill rakers on first arch
    c. Dorsal fin XI–19; a large black spot on the operculum . . . . . *L. vanderbilti*
    cc. Dorsal fin XI–17½ or XI–18½; no black spot on the operculum . . . . . *L. micrognathus*
aa. 3 or 4 branched caudal fin rays . . . . . *L. higmani*

Lonchopisthus micrognathus (Poey, 1860)

Poey (1860, p. 287) based his description of *Opisthognathus micrognathus* on a single specimen 110 mm long. Gill (1862, p. 241) proposed the genus *Lonchopisthus* for Poey's species, listing as generic characters the "normal maxillaries, moderately small scales, and lanceolate caudal fin." Unfortunately several specimens labeled *Opisthognathus micrognathus* were sent to the United States by Poey and have been considered syntypes or cotypes by the institutions which received them (USNM 7485; MCZ [Harvard] 12515 and 12517; see Howell y Rivero, 1938, p. 217). Since Poey's description included a vertebral count and since all the specimens hitherto thought to be syntypes are intact, it is doubtful whether any one of them is the type specimen. These specimens differ somewhat from Poey's description; the range of counts and

measurements is given in Table 2. With the exception of a small (24 mm.) Cuban specimen, no other specimens can be referred to *L. micrognathus*. The fishes reported by LONGLEY (*in* LONGLEY & HILDEBRAND, 1941, p. 243) cannot be located.

Lonchopisthus vanderbilti Mowbray, 1928

This species, described by MOWBRAY (*in* BORODIN, 1928, p. 30, pl. 5 fig. 1) [1]) can be distinguished by its gill raker count (21 + 39) = 60) in combination with its coloration (opercular spot present; presumably absent in *L. micrognathus*), its shallow caudal peduncle (6.8 percent of standard length *cf.* greater than 8 percent), its somewhat smaller head and shorter pectoral fin (Table 2) and its lack of branched caudal fin rays. Considerably more study material will be needed to adequately characterize this species. I believe that *L. vanderbilti* is a valid species.

Two specimens are included in Table 2 which were loaned to me by the Chicago Natural History Museum (CNHM 61701 and 61319). The larger of these was collected on the Campeche Bank, Gulf of Mexico; the smaller is from the western Gulf of Mexico, off northern Mexico. Both are in good condition. For reasons which are largely subjective (*e.g.* the shape of the head and some proportional differences), I believe that these specimens represent an undescribed species of *Lonchopisthus* related to *L. vanderbilti*. Since adequate material of neither species is available, I leave the further study of this western Gulf population to the future ichthyologist who can collect and study such series.

Lonchopisthus lindneri Ginsburg, 1942

This species was described by GINSBURG (1942, p. 360) from three small specimens taken off Texas and Louisiana in the Gulf of

[1]) The holotype (and only known) specimen was made available for study by the Curator of the Vanderbilt Museum, Centerport, Long Island, New York. Long exposure to the bright lights of a display case and the copper wire by which it was affixed to a glass display plate have not increased its usefulness as a scientific specimen. The measurement of least depth of the caudal peduncle cannot be accurately determined, nor can caudal fin ray counts be completed, because the peduncle had been bound with fine copper wire for display mounting. This fish is also hard and brittle, especially when compared to the rather gelatinous POEY specimens of *L. micrognathus*.

Mexico. GINSBURG did not compare his species with *L. vanderbilti*, the description of which he apparently overlooked. He did compare his material with the two U. S. National Museum specimens labeled "syntypes" of *L. microgmathus* (USNM 4785), as did MYERS (1935) in his review of the opisthognathid genera, but I have pointed out above that neither is the "individu décrit" by POEY.

However, the gill raker count (less than 56 on the first arch), lack of opercular spot and vertical cross-banding, and the general configuration of the head distinguish *L. lindneri* from its congeners. The type specimen is shown in Figure 42, and the counts and proportional measurements are given in Table 2.

I wish to record my appreciation as regards the individuals who have generously contributed specimens and information to this study: Dr. C. R. ROBINS, Marine Laboratory, University of Miami; Mr. LOREN P. WOODS, Curator of Fishes, Chicago Natural History Museum; Mrs. MYVANWY DICK, Department of Fishes, Museum of Comparative Zoology, Harvard University; and Mr. WOODHULL B. YOUNG, Vanderbilt Museum, Centerport, New York.

REFERENCES

BORODIN, N. A., 1928. Scientific results of the yacht "Ara" expedition during the years 1926 to 1928, while in command of William K. Vanderbilt. Fishes. *Bull. Vanderbilt Oceanog. Mus. 1*, art. 1, p. 1–37, 2 maps, pl. 1–5 excl.

GILL, THEODORE N., 1862. Remarks on the relations of the genera and other groups of Cuban fishes. *Proc. Acad. Nat. Sci. Philadelphia 14*, p. 235–242.

GINSBURG, ISAAC, 1942. Seven new American fishes. *Journ. Washington Acad. Sci. 32*, p. 364–370.

HOWELL Y RIVERO, LUIS, 1938. List of the fishes, types of Poey, in the Museum of Comparative Zoölogy. *Bull. Mus. Comp. Zoöl. 82*, p. 169–227.

LONGLEY, WILLIAM H., & HILDEBRAND, SAMUEL F., 1941. Systematic catalogue of the fishes of Tortugas, Florida. *Carnegie Inst. Washington Publ. 535* (Papers from Tortugas Lab., vol. 34), 331 pp., 34 pl. excl.

MYERS, GEORGE S., 1935. A new genus of opisthognathid fishes. *Smithsonian Miscl. Coll. 91*, no. *23*, 5 pp.

POEY, FELIPE, 1858–61. *Memorias sobre la historia natural de la isla de Cuba, acompañadas de sumarios Latinos y extractos en Francés 2*, 442 pp., 19 plates excl.

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Gobionellus stigmalophius, a New Goby from the Gulf of Campeche and the Great Bahama Bank

Giles W. Mead and James E. Böhlke

THE specimens which are described below are from two sources. The holotype was taken on an expedition from the Academy of Natural Sciences of Philadelphia, under the sponsorship of Mr. Charles C. G. Chaplin. This was a part of the Bahama Shore Fish Program being conducted by the Academy's Department of Ichthyology and Herpetology.

The two larger specimens, the paratypes, were taken during the course of the exploratory fishing and gear development work being carried on in the tropical Atlantic by the U. S. Fish and Wildlife Service.

While the type specimens are from rather widely separated geographic localities and differ enough in size to render comparison difficult, they agree well in scale and fin ray counts, and in general proportions, characters which Ginsburg (1932) considered most important in separating the species of *Gobionellus*. The smallest specimen has been selected as the type in preference to the others because it alone is in good condition.

Gobionellus stigmalophius *sp. nov.*

Fig. 1

Holotype: ANSP 81233, 49.0 mm. in standard length (68.5 mm. total length), from station 402, north side of sandy point forming the western tip of Green Cay, Bahamas: Lat. 24° 02′ 25″ N., Long. 77° 11′ 00″ W.; July 15, 1957; water: slightly murky; vegetation: none; time: 1500–1700 hours; bottom: clear sand; distance from shore: to about 50 feet; depth of capture: to about 5 feet; method of capture: rotenone; collectors: Charles C. G. Chaplin and Gordon Chaplin, H. Radclyffe Roberts and Radclyffe Roberts, and James Böhlke; water temperature: 87°F.

Paratypes: USNM 159590, 1, 76.5 mm. in standard length (118.5 mm. total length), collected by the U. S. Fish and Wildlife Service research vessel Oregon at station 1059 (cruise 22): Gulf of Mexico (Gulf of Campeche): Lat. 18° 43′ N., Long. 93° 29′ W. Collected with a 40-foot commercial shrimp trawl dragged over a terrigenous gray mud bottom at a depth of 25 fathoms; May 16, 1954; 1855 to 1910 hours.

ANSP 81855, 1, 59.5 mm. in standard length, taken at *Oregon* station 1058 (cruise 22): Gulf of Mexico (Gulf of Campeche): Lat. 18° 45′ N., long. 93° 20′ W. Collected with a 40-foot shrimp trawl on a mud bottom at a depth of 22 fathoms; May 16, 1954; 1642 to 1750 hours.

Diagnosis: Teeth in upper jaw uniserial; those in lower biserial anteriorly, uniserial posteriorly. All teeth canoid, but no enlarged canine teeth. Dorsal VI, 13½; anal 14½; pectoral 21 or 22. Caudal fin long and pointed, its length from 1.8–2.5 in the standard length. Anterior body scales cycloid, some of the posterior ones, above the midline, ctenoid; more than 88 in horizontal series. Cheek, opercle and predorsal area scaleless. Ventral fins united and long, extending to origin of anal fin. Membrane between spines of ventral fins well developed. No filamentous extension on spines of first dorsal fin. Anterior nostril with a short tube. A prominent black spot on the spinous dorsal posteriorly.

Description: Body elongate and compressed, tapering evenly from the head to the stout caudal peduncle. Greatest depth of body at the insertion of the ventral fins, 1.4–1.6 in length of head. Depth of caudal peduncle 2.4–2.6 in length of head. Head broader than body, its width about two-thirds of its depth. Snout obtuse and uniformly convex, its length 2.2–3.2 in length of head. Mouth terminal, the upper jaw teeth exposed when the mouth is closed. Gape nearly horizontal, its angle beneath pupil; the larger the individual the further back the angle. Anterior nostril with a short tube located above lip and below a horizontal with lower edge of eye. Posterior nostril larger than anterior, elliptical, level with lower margin of pupil. Eye small, round, superior and encroaching on dorsal profile. Diameter of eye 4.1–4.8 in length of head. Interorbital narrow and concave. Gill opening wide, extending from above the upper end of the pectoral base to the level of the ventral base; width of the isthmus 4.6 to about 6 in length of head.

Teeth on premaxillaries and dentaries only. These jaw teeth are conical, slightly recurved and form a single series which extends from snout to angle of gape and, on lower jaw, from the symphysis to the angle. Those on upper jaw are in a single row. Those on the lower are uniserial

Fig. 1.—*Gobionellus stigmalophius,* holotype, 49.0 mm. in standard length; ANSP 81233. Drawn by Stephen P. Gigliotti

laterally but biserial anteriorly. A few small teeth are present between the inner and outer rows anteriorly, particularly on the largest specimen. The teeth of the upper jaw are about twice as long and strong as those of the lower. The inner series of mandibular teeth is present only anteriorly and is composed of conical teeth comparable in shape, although somewhat smaller in size, to those of the outer series. The fold of skin across the roof of the mouth behind the jaws is rugose; the papillae forming this patch are slightly stiffened but are not teeth. This patch of papillae is in no way comparable to the inner row of teeth displayed by the specimens of *Gobionellus hastatus* and *G. oceanicus* which we have examined. A patch of well-developed sharp teeth is present on each superior and inferior pharyngeal bone. Vomer and palatines edentulous.

Gill rakers short, flattened and triangular. One on upper limb of first arch, five on the lower. (Since a dissection was required to reveal the branchial chamber, only one paratype was examined.)

Dorsal: VI, 13½. Anal: 14½. Pectoral: 21 or 22.

Distance from snout to origin of dorsal fin 3.1–3.2 in standard length. Spinous dorsal high, the spines increasing in length to the fourth or fifth. Longest spine 1.3–1.5 in length of head. Second dorsal well separated from first, originating over insertion of anal fin; the posterior rays longest, 1.4–1.6 in length of head. Anal fin similar in shape, its origin, like that of the dorsal, a little in advance of the middle of the body. Posterior dorsal and anal rays, when depressed, extend beyond base of caudal. Caudal lanceolate, the mid-caudal rays longest, with those above and below becoming progressively shorter. Seventeen segmented and 14 divided caudal fin rays. Base of caudal fin scaled. Length of caudal fin 1.8–2.5 in standard length, longest in the largest specimen.

Pectoral fin broad; the middle rays either failing to reach anus or just reaching that point. Length of pectoral, measured from base of uppermost ray, 4.4–4.8 in standard length. Ventral fins united, broad, and extending to origin of anal fin. The two ventral spines are connected by a fold which covers the bases of the fin rays. Length of ventral fin 3.6–4.1 in standard length, slightly longer than the pectoral fin.

Scales in horizontal series between upper end of gill opening and base of caudal 89 to about 102. Scales cycloid anteriorly. Some of those above the midline on the posterior two-thirds of the body ctenoid. The posterior scales slightly larger than the anterior. Head naked. Body scales beginning a short distance behind upper end of gill opening.

Coloration of type (from the specimen which is in perfect condition but whose pattern is already faint, and from an overexposed color slide): The most distinct feature of its pigmentation is the jet black blotch at the posterior end of the spinous dorsal fin. Along the middle of the sides are four equally spaced roundish blotches (there may or may not have been a fifth at the caudal base). Above and between these dorsally are irregular, elongate, largely horizontal markings of the same shade and intensity (on the preserved fish). Anteriorly these dorsal markings become less elongate, some nearly circular, smaller, more irregular and broken up. All of these blotches and markings with darker margins than centers. From the photograph, the markings appear golden or bronze in life, though this is not certain since the colors in the photograph are not true. Some irregular markings on snout, which again seem to have darker margins than centers. Ventral cup dusky. Some narrow linear longitudinal markings on vertical fins; several faint concentric bands on caudal.

Coloration of Campeche Paratypes (from the specimens which are in rather poor condition).—Mid-lateral body blotches not evident. Posterior spinous dorsal blotch very much in evidence on both specimens. Body coloration dusky, darker in the larger specimen. Uper half of body with an irregular dusky pattern which is more pronounced anteriorly. Black band on free edge of each scale in dorsal half of body. The band on the anterior scales more prominent. Little or no black on scales on ventral half of body. First dorsal fin darker than body, with alternating light and dark patches along spines. Second dorsal and upper half of caudal dusky, with similar light and dark blotches. Distal half of caudal darker than proximal. Anal fin and lower half of caudal uniformly stippled and without pattern. Pectoral fin colorless in the smaller specimen. On the larger, the membrane over each ray is pigmented. Alternating light and dark patches on the membrane between the ventral fin rays. The chromatophores are more dense distally. Buccal cavity and peritoneum dusky.

Measurements, expressed as thousandths of standard length, of the holotype (49.0 mm.) followed, in parentheses, by those of the paratypes (76.5 and 59.5 mm., respectively): greatest depth of body, 184 (196, 185); greatest width of body, 127 (105, 109); least depth of caudal peduncle, 104 (111, 109); greatest depth of head, 190 (170, 193); greatest width of head, 167 (144, 176); length of head 273 (268, 277); length of snout, 087 (105, 126); horizontal diameter of eye, 057 (059, 067); width of fleshy interorbital, 021 (030, 025); length of premaxillary, 120 (137, 118); eye to angle of gape, 072 (085, 084); snout to origin of dorsal, 316 (314, 319); snout to origin of anal, 510 (497, 513); snout to upper end of base of pectoral, 281 (274, 286); snout to insertion of ventral, 237 (248, 286); insertion of ventrals to origin of anal, 278 (229, 269); distance from upper end of base of pectoral to tip of pectoral, 224 (209, 227); length of ventral fin, 276 (255, 244); longest first dorsal spine, 210 (189, 185); longest second dorsal ray, 168 (189, 151); length of midcaudal ray, 398 (549,—).

Discussion.—Among the American gobies, *Gobionellus stigmalophius* is most closely related to the more highly modified of its congeners, *G. hastatus* Girard, *G. oceanicus* Gronow and *G. gracillimus* Ginsburg (see Ginsburg, 1932: 6, 35–44; 1953: 24). *G. stigmalophius* resembles these three species in the large number and small size of the scales, the number of second dorsal and anal fin-rays, the greatly attenuated caudal fin and the general form of the body. The new species differs, however, from *G. oceanicus* and *G. hastatus* in several significant respects: uniserial teeth in the upper jaw and biserial in the lower; scaleless operculum; failure of the body scales to extend forward to the upper end of the gill opening; and the greatly elongated ventral fins (which reach to, or beyond, the origin of the anal fin in *G. stigmalophius*). A greater similarity exists between *Gobionellus gracillimus* Ginsburg (1953: 24) from the northern coast of the Gulf of Mexico and our species. Although no figure accompanies the type description of *G. gracillimus* it is apparent that in general shape of the body and fins, length of caudal fin, and type of squamation, the species are quite similar. *G. stigmalophius*, however, has uniserial premaxillary teeth while those of *G. gracillimus* occur in a narrow band. Our specimens have a scaleless area on nape between the origin of the dorsal fin and the snout while in *G. gracillimus* this area is scaled. Our fish have 21 or 22 pectoral rays; *G. gracillimus* has 18 to 20. Although Ginsburg's specimens were larger than those reported here it is unlikely that these differences are associated with body size. There are also differences in body proportions. Our species has a deeper body (18.4–19.6 percent of standard length *cf.* 11.0–15 in *gracillimus*), deeper head (17.0–19.3 percent *cf.* 10.5–13), wider head (14.4–17.6 percent *cf.* 9–10.5), longer snout (8.7–12.6 *cf* 6.5–7.5), larger eye (5.7–6.7 *cf.* 3.5–5), and longer ventral fins (24.5–27.6 *cf.* 17.5–21.5).

It may be argued that by having uniserial dentition in the upper jaw *Gobionellus stigmalophius* should more properly be placed in Bleeker's genus *Oxyurichthys* or among the gobies referred to Gill's *Euctenogobius* by Jordan, Evermann and Clark (1930: 442), Meek and Hildebrand (1928: 874, pl. 87) and others. The species included in *Euctenogobius* are separable from *Gobionellus* by having a uniserial row of teeth in the upper jaw and a narrow band of teeth in the lower. Ginsburg (1933: 19; 1953: 23) has discussed the problem and his union of the two genera seems well justified. Although *Gobionellus stigmalophius* is in many respects similar to *G. liolepis* (Meek and Hildebrand) from Balboa, Panama, the long ventral fins, scaleless nape, cheek and operculars, and the greatly elongate caudal fin are among many characteristics in which the two differ. *Gobionellus* and *Oxyurichthys* are also quite similar. Ginsburg (1932: 5) has carefully pointed out that they may be separable by the dentition of the upper jaw: "A single row in *Oxyurichthys*, more than one row in *Gobionellus*." If our species is to be included in *Oxyurichthys*, however, the diagnosis of that genus would have to be emended, just as the characterization of *Gobionellus* must be slightly changed if it is to include *G. stigmalophius* and the species once placed in *Euctenogobius* but referred to *Gobionellus* by Ginsburg. Our species bears a closer resemblance to *Oxyurichthys* than to any of the other Indo-Pacific genera discussed by Koumans (1931; 1953), but is at variance with his diagnosis in several respects: the dentition of the lower jaw, the non-tubular anterior nostril, the scalation, etc. An attempt to reallocate the Pacific and African species related to *Oxyurichthys* leads to difficult situations and a natural

definition of *Oxyurichthys* must await a reanalysis of the genera on a world-wide basis.

For zoogeographic reasons our fish should more closely resemble the African than the Indo-Pacific species of *Oxyurichthys*. *O. occidentalis* (Boulenger, 1909: 431) is the sole representative of the genus along the West African coast. This species (Boulenger, 1916: 39; Fowler, 1936: 1012) agrees with our fish in the possession of uniserial dentition in the upper jaw but in few other respects. *O. occidentalis* has fewer scales (60–62 in lateral series), non-tubular nostrils, scaled cheeks and operculars, and "ciliated" scales—characters at variance with our specimens. From this discussion it is obvious that these genera, although closely related, are at present poorly defined. Our species is considered here a highly modified *Gobionellus*, and with this inclusion the generic limits of *Gobionellus* and *Oxyurichthys* closely approach one another.

Literature Cited

Boulenger, George Albert. 1909. Descriptions of three new fishes from Portuguese Guinea. *Ann. Mag. Nat. Hist., ser. 8, vol. 4, pp. 429–431.*

———. 1916. Catalogue of the fresh-water fishes of Africa in the British Museum (Natural History), *vol. 4, 392 pp. British Museum.*

Fowler, Henry W. 1936. The marine fishes of West Africa, based on the collection of the American Museum Congo Expedition, 1909–1915. *Bull. American Mus. Nat. Hist., vol. 70, pt. 2, pp. 607–1493.*

Ginsburg, Isaac. 1932. A revision of the genus Gobionellus (family Gobiidae). *Bull. Bingham Oceanographic Coll., vol. 4, art. 2, 51 pp.*

———. 1933. Description of new and imperfectly known species and genera of gobioid and pleuronectid fishes in the United States National Museum. *Proc. U. S. Nat. Mus., vol. 82, 23 pp.*

———. 1953. Ten new American gobioid fishes in the United States National Museum, including additions to a revision of Gobionellus. *Journ. Washington Acad. Sci., vol. 43, no. 1, pp. 18–26.*

Jordan, David Starr, Barton Warren Evermann, and Howard Walton Clark. 1930. Check list of the fishes and fishlike vertebrates of North and Middle America north of the northern boundary of Venezuela and Colombia. *Rep. U. S. Comm. Fish for 1928, pt. 2, 670 pp.*

Koumans, Frederik Petrus. 1931. A preliminary revision of the genera of the gobioid fishes with united ventral fins. *176 pp., Lisse.*

———. 1953. Gobioidea, *in* Weber, Max, and L. F. de Beaufort, *Fishes of the Indo-Australian Archipelago, vol. 10, 423 pp., Leiden.*

Meek, Seth E. and Samuel F. Hildebrand. 1928. The Marine Fishes of Panama. *Field Mus. Nat. Hist. Publ. no. 249, Zoological Series, vol. 15, pt. 3, pp. 709–1045, pls. 72–102.*

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TARACTES ASPER AND THE SYSTEMATIC RELATIONSHIPS OF THE STEINEGERIIDAE AND TRACHYBERYCIDAE

By Giles W. Mead and G. E. Maul

With One Plate

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No. 6 — Taractes asper *and the Systematic Relationships of the Steinegeriidae and Trachyberycidae*

By Giles W. Mead[1] and G. E. Maul[2]

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INTRODUCTION

In an earlier paper one of us reviewed the status of certain species of bramid fishes (Mead, 1957). Excluded from that account were several nominal species related to *Taractes longipinnis* which were so poorly known that a comparison of them with the more common *Taractes* was impossible. This study is concerned principally with three such forms: *Taractes asper* Lowe, 1843, *Steinegeria rubescens* Jordan and Evermann, 1887, and *Trachyberyx barretoi* Roule, 1929.

Our study has indicated that the genus *Taractes* contains species of two distinct types, one with a deep body, the other with a less deep one. Two subgenera are recognized for these types: *T.* (*Taractichthys,* new), and *T.* (*Taractes*) respectively. We have also concluded that *Taractes asper* is not the juvenile of *Taractes longipinnis* as has customarily been assumed, but is a valid species of *Taractes* (*Taractes*), the adult of which is un-

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known. The series of specimens described by Maul from Madeira as *Trachyberyx barretoi* are considered identical with *Taractes* (*Taractes*) *asper*. Maul's fishes, which are questionably identified with Roule's type of *Trachyberyx barretoi* and on which Maul based the berycoid family *Trachyberycidae*, are not berycoids but bramids. We have also found that the juvenile fish described as *Steinegeria rubescens* (*Steinegeriidae*) is closely related to *Taractes* (*Taractes*) *asper*. An account of the relationships of these species and the nomenclatorial consequences of our classification follows below.

In addition to comparative bramid and berycoid specimens contained in the Museu Municipal do Funchal and the U. S. National Museum, our study material includes the following specimens:

The type of *Steinegeria rubescens*.

A juvenile *Steinegeria rubescens* from the Gulf of Mexico (United States Fish and Wildlife Service exploratory vessel *Oregon* station 1473: 24° 48′ N. Lat., 91° 40′ W. Long.; March 26, 1956; from the stomach of an *Alepisaurus ferox* which was caught on a tuna long-line).

An adult from the Gulf of Mexico about 200 miles south of Mississippi (caught on a tuna long-line by the commercial fishing vessel *Sirocco*).

An additional juvenile, tentatively referred to *T. rubescens*, from the Pacific off Upolu Point, Hawaii (taken by the U. S. Fish and Wildlife Service research vessel *Hugh M. Smith III*, April 17, 1950; from the stomach of a pelagic octopod, *Eledonella* sp., which in turn was taken from the stomach of an *Alepisaurus ferox*).

The series of Madeiran specimens which were discussed by Maul (1954:18) as *Trachyberyx barretoi* and additional juvenile specimens of the same species from Madeira.

We are indebted to the Curators of the Museum of Comparative Zoology, Harvard University, and the Natural History Museum, Stanford University, for making their specimens of bramid and berycoid fishes available to us. Several individuals have provided specimens or supplementary information, and we wish here to record our appreciation to Prof. Umberto d'Ancona, Istituto di Zoologia e Anatomia Comparata, Padova, Italy; Dr.

G. Belloc, Institut Océanographique, Monaco; and to Dr. Albert L. Tester, John W. Reintjes and Harvey R. Bullis, Jr., of the U. S. Fish and Wildlife Service.

Taractes

In their careful study of a western North Atlantic *Taractes*, Bigelow and Schroeder (1929) separated the species of *Taractes* from *Brama* on the basis of the number of scales in a longitudinal series. They included seven nominal species within the genus: *T. asper* Lowe, *longipinnis* (Lowe), *brevorti* (Poey), *raschi* (Esmark), *princeps* Johnson, *saussuri* (Lunel) and *steindachneri* (Döderlein). These species, and the two which were described subsequently (*T. platycephalus* Matsubara and *T. miltonis* Whitley), were later reviewed by Mead (1957). In both of these papers *T. asper* was considered a dubious species but retained as distinct from its congeners. The results of the two studies differ principally in the treatment of *T. princeps* Johnson, which Bigelow and Schroeder thought had best be considered distinct from *T. longipinnis*, and *T. raschi*. *T. asper* will be discussed more fully below, and the specific differences, if any, between *T. princeps* and *T. longipinnis* will not affect our present understanding of *Taractes*. *T. raschi* is treated here as a distinct species.

The great changes in form of vertical fins, type of scalation and the like during growth has been troublesome to those who have attempted taxonomic studies of the bramids. A feature which separates these nine species into two natural groups is the relative depth of the body, and correlated with it the dorsal profile of the head. This is recognized here as a subgeneric characteristic, although a test of its validity must await the capture of full developmental series of each species.

The type figures of *Taractes raschi* (see Smitt *et al.*, 1892-95, fig. 24; Mead, 1957, fig. 4) and *T. platycephalus* (Matsubara, 1936) show shallow-bodied forms with concave foreheads. Measurements taken from Esmark's figure of *T. raschi* show that the greatest depth of body is contained 2.4 times in standard length, 2.7 in fork length, and about 3.1 in total length. These ratios for *T. platycephalus* are: 2.3, 2.8 and 2.9. (We will note below that the adult *Taractes rubescens* is in this shallow-bodied group.

The comparable depths in standard, fork and total length are: 2.5, 2.7 and 3.1. Our analysis of *T. asper* also suggests that its adult should be placed here.) We propose the subgenus *Taractes* (*Taractes*) for these four species.

Differing from this group are the adult *Taractes* which are more frequently caught (for example, those reported by Bigelow and Schroeder, 1929; Fitch, 1953:546; Whitley, 1938:191; Fowler, 1956). In these the foreheads are convex and steeply inclined; the fins, although variable, are more strongly falcate; and the general form is somewhat rhomboidal. In the deep-bodied Atlantic specimen reported as *T. princeps* by Bigelow and Schroeder (1929) the maximum depth is contained 1.9 in standard length, 2.1 in fork length and about 2.6 in total length. These measurements on smaller Atlantic deep-bodied specimens are: 1.6-2.0, 1.8-2.1 and 1.8-2.6. Published figures of *T. saussuri* Lunel, *T. steindachneri* Döderlein and *T. miltonis* Whitley identify these species with the deep-bodied forms. Poey's description of *T. brevorti* also defines a deep-bodied species.

Fortunately, Johnson recorded standard length as well as "total" length for one of his specimens of *T. princeps*. The body depth is contained 1.9 and about 2.6 in these lengths respectively, thus establishing his species as a deep-bodied form. Lowe (1843:82) was less precise in his original account of *T. longipinnis*, for he says only that, "The example seen measured eighteen inches and a quarter in length, and was eight inches deep at the origin of the dorsal and anal fins," a ratio of 2.28. If he was referring to standard length, *T. longipinnis* would be among the shallow-bodied species distinct from *T. princeps* and allied to *T. raschi*. Nowhere in his 1843 paper does he define "length" and, since there are no figures, a more definite meaning cannot be deduced from his account of other species there described. A perusal of his "Fishes of Madeira" (1843-60), however, has convinced us that Lowe's "length" refers to a total or overall length, since the two terms are used interchangeably in that publication and the morphometric ratios of the fishes there described and figured are given in terms of a total, not a fork or standard, length. *Taractes longipinnis* can thus be placed among the deep-bodied species, for the ratio 2.3 is within the range of other deep-bodied forms but not within that of the rarer less-deep species.

Within this second subgenus of *Taractes, T.* (*Taractichthys*), we therefore include these named deep-bodied forms: *longipinnis, brevorti, princeps, saussuri, steindachneri* and *miltonis.*

We can turn now to the three named species which are the principal concern of this paper: *Taractes asper, Steinegeria rubescens* and *Trachyberyx barretoi.*

Taractes asper Lowe, 1843

Lowe based *T. asper* on a single "plain and sober-coloured little fish" from Madeira. One of us has searched the collections of the British Museum for this and other of Lowe's types, but could not find *T. asper.* Since we believe that this fish bears a close resemblance to those later described under the generic names *Steinegeria* and *Trachyberyx,* and since *T. asper* is the type species of *Taractes,* we quote here Lowe's original description of *Taractes* and *T. asper.* In the absence of a figure and of the type specimen, this description constitutes our entire knowledge of that species.

"Gen. *Taractes,* nob.

"*Char. Gen.* — *Corpus* ovatum compressum (ad finem pinnae dorsalis analisque abrupte in caudam contractum), squamis cycloideis retrorsum aculeato-umbonatis muricato-asperum. *Caput* squamosum; oculis magnis; rostro brevissimo simo; rictu magno subverticali; dentibus *Bramae* similibus subscobinatis recurvis, externis majoribus; palatinis vomereque armatis. *Operculum* simplex inerme. *Praeoperculum* basi eximie dentato s. subcalcarato; suboperculo interoperculoque denticulatis.

"*Pinnae* malacopterygiae, s. omnes radiis mollibus. *Ventrales* subjugulares. *Pinna dorsalis analisque* unica conformis lata; *caudalis* simplex integra rotundata. *Membrana branchiostega* septem-radiata.

"*Squamae* magnae trapeziformes postice emarginatae cycloideae; umbone in aculeum recurvato-erectum producto.

"*Taractes asper.*

D. 5 + 28; A. 3 + 20; P. 17; V. 1 + 5; C. $\frac{4 + \text{VIII}}{3 + \text{VII}}$; M. B. 7; Squamae corporis in serie longitudinali 43 fere.

"The generic name imposed at its first discovery on this particularly interesting, though plain and sober-coloured little fish, expresses the difficulty experienced in settling its relations of affinity, which are

indeed so obscure and complicated, that but for the subsequent discovery of *Brama longipinnis*, with its similarly, though contrariwise, hooked scales, its true position, next to *Brama*, with analogies to many other families (e.g. *Zenidae, Caproidae, Scombridae*), must have remained in abeyance.''

Immediately above his account of *Taractes*, Lowe described a similar fish, *Brama longipinnis*. Later workers, for want of a better knowledge of *Taractes asper*, have considered this species to be a young stage of *T. longipinnis*. This practice is no longer

Figure 1. Juvenile *Taractes* (*Taractichthys*) *longipinnis*, about 30 mm. in standard length. (Museu Municipal specimen no. 345; drawn by G. E. Maul.)

appropriate. Mead (1957) has described a 74 mm. juvenile *Taractes longipinnis* (with which he considered *T. princeps* identical), and a 30 mm. fish which can best be referred to this species (Fig. 1) was collected by Maul at Madeira and is now in the Museu Municipal, Funchal. These juveniles, and the published descriptions of adults of various sizes (Barnard, 1948:374; Bigelow and Schroeder, 1929; Fitch, 1953:539; Whitley, 1938; etc.) differ in several aspects from Lowe's type description of *T. asper*. His fish was said to have a spine-bearing preoperculum,

uniformly broad dorsal and anal fins, and a simply rounded caudal fin. These are not attributes of the young of *Taractes longipinnis,* for the denticulations of the operculum and preoperculum of the young can hardly be called spines, both the dorsal and anal fins become falcate at a very small size, and the caudal fin changes from a simple fork in the young to the deeply concave, scombrid-like type of the adult. Nor is it likely that Lowe's *T. asper* is the young of one of the other bramid genera: *Brama, Collybus* or *Eumegistus.* We have seen the young of the first two of these and the juvenile *Brama leucotaenia* Fowler,

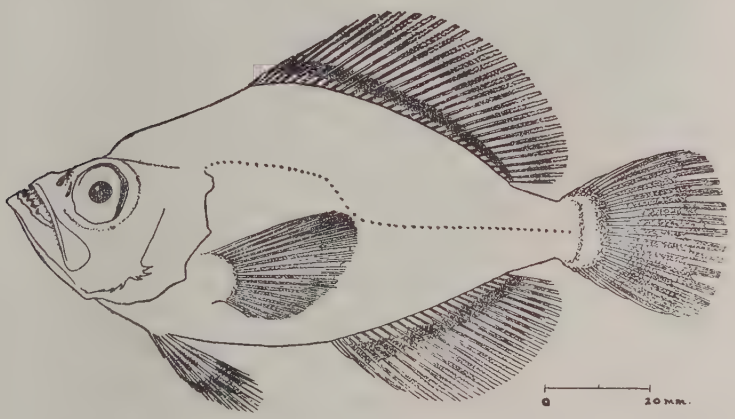

Figure 2. *Taractes* (*Taractes*) *asper,* about 110 mm. in standard length, from Madeira (from Maul, 1954:20).

which may represent the young of the third. On the other hand, Lowe's description of *T. asper* does agree well with the fishes later described from Madeira as *Trachyberyx barretoi* and from the Gulf of Mexico as *Steinegeria rubescens.* It differs from these principally in the number of scales in a lateral series (see Table 1) and in the presence of vomerine teeth. (Lunel, 1866, found the presence of vomerine teeth to be variable in some bramids, while Fowler (1936:652) suggested that they disappear with growth.) The counts of *Taractes asper* given by Lowe are com-

pared with those of our other material in Table 1. We have concluded that Lowe's *T. asper* is conspecific with Maul's Madeiran *Trachyberyx barretoi.*

Trachyberyx barretoi Roule, 1929

The type of *Trachyberyx barretoi* was caught off Madeira and described as a new genus and species of berycoid related to *Trachichtodes.* Subsequently a series of Madeiran specimens was referred to this species by Maul and formed the basis for the account of his new and monotypic family Trachyberycidae (Maul, 1954:18). *Trachyberyx barretoi* is discussed here because Maul's specimens are not berycoids but bramids of the genus *Taractes,* closely allied to and probably identical with Lowe's "plain and sober-coloured little" type of *Taractes asper.* However, we have not definitely included the genus *Trachyberyx* Roule in the synonymy of *Taractes* or his species *barretoi* in that of *asper* because we have not been able to examine Roule's holotype, which is in the Institut Océanographique, Monaco. The general configuration of the specimen given in Roule's account is similar to that of the specimens reported by Maul (1954) and of the type of *Steinegeria rubescens.* It differs from these in fin placement, scale spines and preopercular spines. Professor d'Ancona, who examined this type for us, has forwarded information which has helped to clarify the status of Roule's species and to correct some of the errors in his description.

Professor d'Ancona has recounted the ventral fin of Roule's type and found it to be composed of a spine and five rays. Roule reported a count of I-6, the only characteristic given in the original account by which *T. barretoi* could be allied with the berycoids. On the other hand, the type has nineteen principal caudal rays (d'Ancona, personal communication), a berycoid characteristic, as opposed to the caudal count of I-15-I in Maul's Madeiran series and in all other specimens of *Taractes* which we have seen. Roule's specimen also differs in the type of spination on the scales of the caudal peduncle, for those in the midlateral series of the caudal peduncle are not notably stronger than those adjacent to them, in contrast to both Maul's specimens and the

Gulf of Mexico *T. rubescens.* Professor d'Ancona has also redescribed the preopercular spines as "approximately so arranged as in Fig. 5 of Maul's (1954) paper, not in the way represented in Roule's picture (Bull. Inst. Océan. 546)." The preopercular spines are very distinctive in our Madeiran and Gulf of Mexico juveniles. In summary, we have not been able to determine to which order or genus the type of *Trachyberyx barretoi* should be referred but suspect that it may be a species of *Taractes.*

We have dissected one of the Madeiran specimens on which the Trachyberycidae was based and have found it to differ in several important respects from the original diagnoses of the Berycoidei provided by Starks (1904:602), Regan (1911:2) and Berg (1947:467). There seems to be no orbitosphenoid, and the interorbital septum is double, at least dorsally. The supplementary maxillary is small and the maxillary is not articulated with the vomer anteriorly. The exoccipitals are separate from one another and from the basioccipital. The basioccipital is concave; the center of the concavity is slightly above the center of the vertebra. The insertion of the actinosts of the pectoral fin are equally divided between the hypercoracoid and the hypocoracoid. There are 42 (41 + 1) vertebrae. The ventral fin is composed of a spine and five branched and segmented rays. The caudal count is I-15-I. This combination of characters removes the *Trachyberyx barretoi* of Maul from the berycoids as currently understood.

We believe that the *Trachyberyx barretoi* of Maul is identical with *Taractes asper* Lowe. The adult of this form is unknown. The young, however, is closely related to the Gulf of Mexico *T. rubescens,* the adult of which is shown in the Plate. By analogy with *T. rubescens,* we expect the adult of *T. asper* to be a shallow-bodied species similar to *T. rubescens* and *T. raschi.*

Steinegeria rubescens, Jordan and Evermann, 1887

Steinegeria rubescens (Figs. 3-4) was described as a new genus and species of bramid and was based on a specimen taken from the stomach of a red "grouper" caught in the Gulf of Mexico off Pensacola, Florida. This fish, in very poor condition, is now in the United States National Museum (US 37991). Subsequent to its first public description, Jordan and Evermann

(1896 :960) elevated it to family status as the Steinegeriidae, a family closely related to the Bramidae. No figure of *S. rubescens* has heretofore been published, and although the Steinegeriidae was retained as a family by Jordan and his co-authors (*e.g.* Jordan, Evermann and Clark 1930 :266), other writers, who have been unable to determine the proper position of *S. rubescens* from the description alone, have treated *Steinegeria* as a dubious genus of bramids.

Figure 3. Holotype of *Steinegeria rubescens* (*Taractes* (*Taractes*) *rubescens*), 96.5 mm. in standard length, from the Gulf of Mexico. (Drawn by Mildred H. Carrington.)

The very poor condition of the type specimen is a handicap. The cheek bones and fins are partially digested and some elements are missing altogether. The spined scales are present, but the enlarged spines which occur on the caudal peduncle are evident on one side only. The distinctive preopercular spines which are diagnostic of the Madeiran, Gulf of Mexico, and Hawaiian juveniles are absent from one preoperculum and are highly eroded on the other. The dorsal fin, said by Jordan and Evermann to be divided and thus of taxonomic merit, is composed of partially digested elements which bear indications that they were

once filamentous. Most of these elements are broken, three at their bases. (They are drawn accurately in Figure 3. Juveniles of *T. rubescens* may have a notched dorsal fin.) In addition to the several severe cuts and tears in the body wall, the fish is badly torn above the origin of the anal fin. Consequently our count of that fin as well as the measurements which include this point are of questionable accuracy. This is not a specimen from which we can draw general inferences regarding the population of which it was once a part. In spite of its condition,

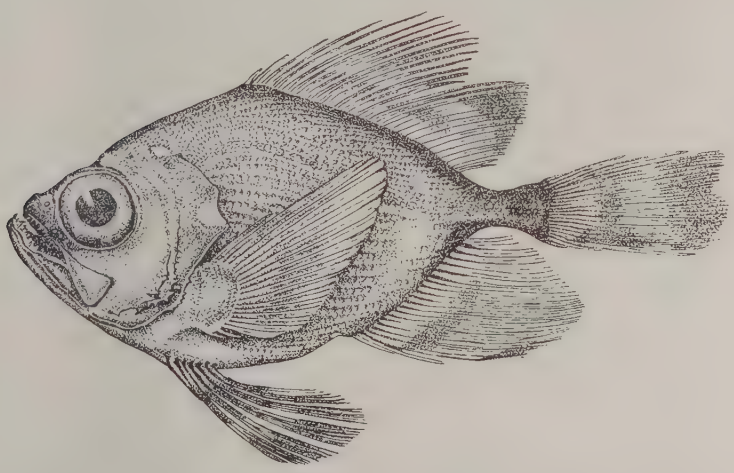

Figure 4. Juvenile *Taractes* (*Taractes*) *rubescens*, about 54 mm. in standard length, from the Gulf of Mexico. (Drawn by Mildred H. Carrington.)

however, we are convinced of its generic relationship to *Taractes*. A comparison of Figures 2 and 3 is offered in support of our view that *Steinegeria* is synonymous with *Taractes* as represented by its type species, *T. asper*.

We have referred two additional Gulf of Mexico specimens to *Taractes rubescens* — a 54 mm. juvenile and a large adult (Fig. 4, and Plate). The adult is particularly instructive, for if we are correct in considering it to be *T. rubescens*, a comparison is pos-

sible between the juvenile and the adult of this species, and between *T. rubescens* and other related species described from adult material. We believe that the caudal fin does indeed change from the rounded form which characterizes the juvenile to the emarginate type of the adult. Such a change is not out of accord with the development of the caudal fin in *T. longipinnis* (Fig. 1; Mead, 1957, Fig. 3). The development of falcate dorsal and anal fins and an increase in the number of branched rays in these fins continues beyond a fish length of 150 mm. and, as should be expected, the preopercular spines characteristic of juvenile *T.*

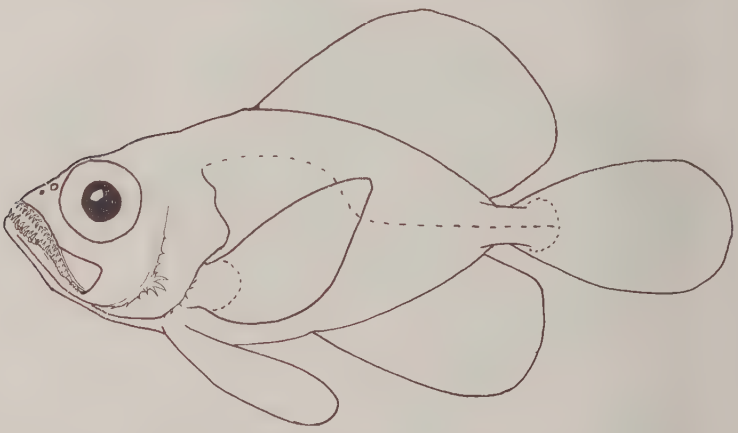

Figure 5. Juvenile *Taractes* (*Taractes*) *asper*, 56.5 mm. in standard length, from Madeira. (Drawn by Mildred H. Carrington.)

asper and *T. rubescens* become overgrown. It is of particular interest that another characteristic of great diagnostic value in the young, the enlarged scale spines on the caudal peduncle, is not a juvenile character but one which persists in the adult. The strong single keel which these scales form on each side of the caudal peduncle distinguishes adult *T. rubescens* from every known adult bramid specimen heretofore reported and vindicates our use of that character for the separation of the Madeiran juveniles of *T. asper* and *T. longipinnis*.

The juvenile of *T. rubescens* is quite distinct from the young Madeiran *T. asper*. The more important differences are included in our key (p. 410). The 29 mm. juvenile from off Hawaii, which is in the collection of the Pacific Oceanic Fishery Investigations, Honolulu (Fig. 6), has been compared with our 54 mm. juvenile from the Gulf of Mexico and a 30 mm. one from Madeira. It is

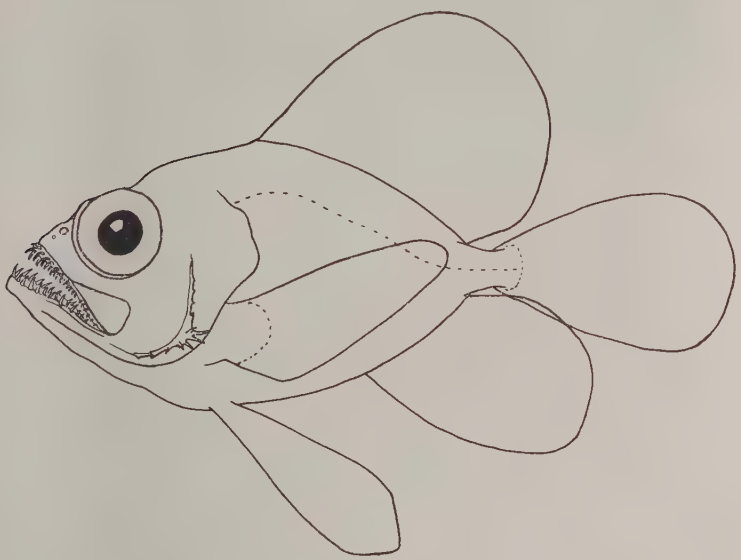

Figure 6. Juvenile *Taractes* (*Taractes*) *rubescens*, 27.5 mm. in standard length, from Hawaii. (Drawn by Mildred H. Carrington.)

similar in most respects to the Gulf specimen. Although there is reason to suspect that the Gulf of Mexico and Pacific populations are different, we are deterred from a full comparison because of the great changes known to accompany the growth of most bramid fishes, and our lack of a western Atlantic specimen of similar size. We will consider the Hawaiian juvenile conspecific with the Gulf of Mexico species until a larger Pacific specimen can be examined.

NOMENCLATURE AND CLASSIFICATION

The recognition of *Taractes asper* as a distinct species, and of *T. asper* and the species related to it as a natural group subgenerically distinct from *T. longipinnis* and its allies, presents nomenclatorial difficulties. Most authors have applied the generic name *Taractes* to the more widely known species related to *T. longipinnis* (*longipinnis, princeps, saussuri, brevorti, steindachneri, platycephalus* and *miltonis*). We believe that *T. asper* is not a young *T. longipinnis* but a fish generically distinct from it. Unfortunately *T. asper* is the type species, and should we

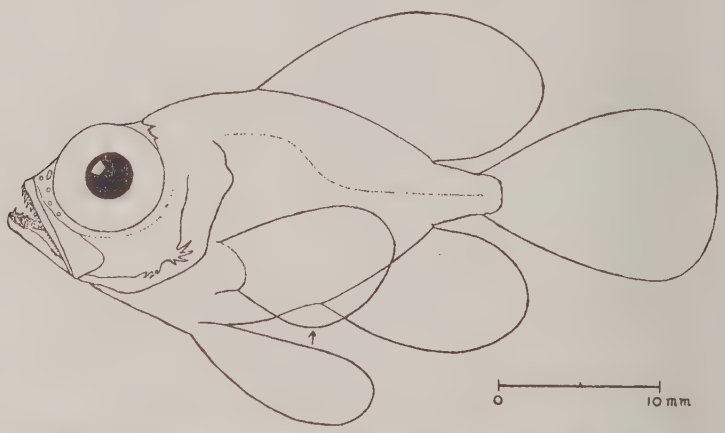

Figure 7. Juvenile *Taractes* (*Taractes*) *asper*, 30 mm. in standard length, from Madeira. (From Maul, 1954:21.)

restrict *Taractes* to its type species, *Steinegeria rubescens*, *Taractes raschi* and *T. platycephalus*, a new generic name would be needed for the commoner forms of the *longipinnis* group. We would not hesitate to propose such a change were our knowledge of Lowe's type specimen more complete or the possibility of its rediscovery more remote. We do not care to take this action without more complete information about that specimen and have consequently chosen to divide *Taractes* into two subgenera:

Taractes, with *T. asper* Lowe as its type species, and *Taractichthys* Mead and Maul, new, with *Brama longipinnis* Lowe as its type species. This compromise fails to recognize nomenclatorially the great differences between these two groups of species; the subgenus is used here as a nomenclatorial convenience as well as an expression of phyletic relationship. It does, however, express the close relationship between species formerly classified in widely separated groups and retains for common current use a widely-used generic name. Should our conclusions be confirmed on the rediscovery of Lowe's type, a phylogenetically more realistic classification can be established. The genera and subgenera of Bramidae (exclusive of Pteraclidae), the species of *Taractes* and the principal synonyms of each are provisionally listed below:

BRAMIDAE

(Bramidae + Steinegeriidae Jordan and Evermann, 1896, + Trachyberycidae Maul, 1954)

Genus Brama

Brama Bloch and Schneider, 1801:98. Type species (subsequent designation by Bory de St. Vincent, 1823 (3): 260): *Sparus raii* Bloch, 1791 (5):95. Generic synonyms:

Lepidotus Asso y del Rio, 1801:38. Type species (monotypy): *Lepidotus catalonicus* Asso, *loc. cit.*

Lepodus Rafinesque, 1810:53. Type species (monotypy): *Lepodus saragus* Rafinesque, *loc. cit.*

Tylometopon Bleeker, 1873:133. Type species *Brama dussumieri* Cuvier and Valenciennes, 1831:294.

Amblytoxotes Bleeker, 1876:311. Type species (monotypy): *Toxotes squamosus* Hutton, 1875:313; 1876:210 (See Weber and de Beaufort, 1936:195).

Genus Eumegistus

Eumegistus Jordan and Jordan, 1922:35. Type species (monotypy): *Eumegistus illustris* Jordan and Jordan, *loc. cit.*, p. 36.

Genus Collybus

Collybus Snyder, 1904:525. Type species (monotypy): *Collybus drachme* Snyder, *loc. cit.*

Genus TARACTES

Taractes Lowe, 1843:82. Type species (monotypy): *Taractes asper* Lowe, *loc. cit.*

Generic synonyms:

Argo Döderlein, in Steindachner and Döderlein, 1883:34, pl. 7. Type species (monotypy) *Argo steindachneri* Döderlein, *loc. cit.*

Steinegeria Jordan and Evermann, 1887:467. Type species (monotypy): *Steinegeria rubescens* Jordan and Evermann, *loc. cit.*

Subgenus *Taractes* Lowe, 1843:82. Type species (monotypy): *Taractes asper* Lowe, *loc. cit.* (Madeira).

Species:

Taractes (*Taractes*) *asper* Lowe

Taractes asper Lowe, *loc. cit.* Günther, 1860:410 (from Lowe).

Trachyberyx barretoi (? non-Roule, 1929) Maul, 1954:18 (juveniles; Madeira).

Taractes (*Taractes*) *raschi* (Esmark)

Brama raschi Esmark, 1862:238 (Norway); 1868:521. Collin, 1874:418. Lilljeborg, 1884-91:310.

Taractes raschi Bigelow and Schroeder, 1929. Mead, 1957:56, pl. 2:4. (from Esmark), 1862, and Smitt *et al.*, 1892-95).

Brama longipinnis (non-Lowe). Smitt *et al.*, 1892-95:80, fig. 24 (part, after Esmark, 1862).

Taractes longipinnis (non-Lowe). Fowler, 1936 (2):653, fig. 293 (part?; figure stated to be after Lowe, who did not publish a figure; probably from Smitt *et al.* after Esmark).

Taractes (*Taractes*) *rubescens* (Jordan and Evermann)

Steinegeria rubescens Jordan and Evermann, 1887:467 (Gulf of Mexico)

Taractes (*Taractes*) *platycephalus* Matsubara

Taractes platycephalus Matsubara, 1936:297, fig. 1 (Japan). Mead, 1957:56 (compared with *T. raschi*).

Subgenus *Taractichthys* Mead and Maul, new. Type species: *Brama longipinnis* Lowe, 1843:82.

Species:

Taractes (*Taractichthys*) *longipinnis* (Lowe).

Brama longipinnis Lowe, 1843:82 (Madeira). Günther, 1860:410 (from Lowe, 1843).

Taractes longipinnis. Steindachner and Döderlein, 1884:174 (on *Argo Steindachneri* Döderlein; Japan). Barnard, 1927:595 (South African adult specimen); 1948:374

(disc. of several S. African specimens). Mead, 1957:52, pl. 1, fig. 1 (Gulf of Mexico adult and juvenile).

Taractes asper (non-Lowe). ?Hilgendorf, 1888:208 (specimen from the Azores said to be deposited in the Museum zu Ponta Delgada).

Taractes princeps Johnson, 1863:36 (Madeira). Bigelow and Schroeder, 1929 (large individual from Nova Scotia). Fitch, 1953:546 ("*Taractes* sp.," adult from California). Fowler, 1956:1 (adult from off New Jersey). Springer and Bullis, 1956:73 (several adult specimens from the Gulf of Mexico).

Argo steindachneri Döderlein, *in* Steindachner and Döderlein, 1883; pl. 7 (Japan).

Taractes steindachneri Jordan, Tanaka and Snyder, 1913:134 (Japan, listed). Matsubara, 1936:297 (compared with *T. platycephalus*).

Taractes miltonis Whitley, 1938:191, pl. 19 (Australia). Mead, 1957:57 (compared with Atlantic *T. longipinnis* Lowe).

Taractes (*Taractichthys*) *brevorti* (Poey)

Brama brevorti Poey, 1861 (2):206 (Cuba)

Taractes (*Taractichthys*) *saussuri* (Lunel)

Brama saussuri Lunel, 1866:185, pl. 2 (Cuba)

It must be understood that these species are among the poorest known of all fishes. Most species are known from very few specimens or from the types alone, and we have had access to few of these. The bramids are renowned for the remarkable changes in body form which take place with growth, and because of this, gross morphological characters which are of unqualified value in the taxonomic study of other groups of fishes are suspect when used in bramid classification. Among these are the presence or absence of a lateral line, shape of vertical fins, presence or absence of vomerine teeth, degree of spination on the scales of the young, and amount of branching in dorsal and anal rays. Some of these questionable characters are used, in the synopsis which follows, to distinguish between species which are known only from the type specimens (e.g. *T.* (*Taractichthys*) *saussuri cf. brevorti; T.* (*Taractes*) *platycephalus cf. raschi*), for we have not been able to examine the type material. We think that the characters used for the separation of the two subgenera and for the species of *Taractes* (*Taractes*) will prove to be valid. In any

event, the synopsis below, based as it is on very few specimens, should be considered tentative.

a. Body deep, its greatest depth less than 2.2 in standard length. Forehead high, convex and steeply inclined.
. . . . . subgenus *Taractichthys*

b. Caudal fin biconcave.

c. Central caudal fin rays extending beyond caudal lobes.
. . . . . *T.* (*Taractichthys*) *saussuri*

cc. Central caudal fin rays not extending as far as tips of caudal lobes.
. . . . . *T.* (*Taractichthys*) *brevorti*

bb. Caudal fin emarginate.
. . . . . *T.* (*Taractichthys*) *longipinnis*

aa. Body less deep, its greatest depth more than 2.2 in standard length. Dorsal profile of snout straight or concave.
. . . . . subgenus *Taractes*

d. Three or four consecutive scales of the midlateral series on the caudal peduncle enlarged and laterally produced to form, in the adult, a strong hard median keel on each side of the caudal peduncle.

e. (Juveniles) Anal fin 23 to 25, the fin originating on a vertical with the seventh to the eleventh dorsal ray. Anterior arch of the lateral line turning abruptly downward under about the eleventh dorsal ray and reaching a midlateral point below the fourteenth. The series of spines on the midlateral scales of the caudal peduncle, which are notably larger than those above and below this series, decrease gradually in length anteriorly. Least depth of caudal peduncle, in juvenile, about ten per cent of standard length. No scaleless area above and behind eye.
. . . . . *Taractes* (*Taractes*) *asper*

ee. (Juveniles) Anal fin 20 to 22, the fin originating on a vertical with the fourteenth to the nineteenth dorsal ray. Anterior arch of the lateral line curving evenly from its origin to a point on the midlateral series of scales below the twentieth dorsal ray. The series of spines on four consecutive midlateral scales of the caudal peduncle are notably and abruptly larger than those immediately anterior to them in this series as well as those immediately above and below them on the caudal peduncle. Least depth of caudal peduncle, in juvenile, about eight per cent of standard length. A scaleless area, about one-third the diameter of the eye, on body above and behind the eye and

separated from the eye by about seven rows of scales. (Western Atlantic and mid-Pacific)
.....*Taractes (Taractes) rubescens*

dd. Scales of midlateral series on caudal peduncle not enlarged; the adult without a midlateral keel on the peduncle.
f. Vomer toothed.
.....*T. (Taractes) raschi*
ff. Vomer toothless.
.....*T. (Taractes) platycephalus*

SUMMARY

A study of a series of specimens from Madeira and the Gulf of Mexico and a comparison of this series with the nominal species of large-scaled bramids (*Taractes*) has led to the inclusion of the genus *Steinegeria* within *Taractes* and the families Steinegeriidae of Jordan and Evermann and Trachyberycidae of Maul within the Bramidae. The species of *Taractes* are divisible into shallow-bodied and deep-bodied forms, and the subgenus *Taractichthys* is proposed for the latter. *Taractes asper*, the type of which was inadequately described, subsequently lost and never illustrated, is applied to a series of Madeiran specimens formerly referred to *Trachyberyx barretoi*. Allied to this series are two juveniles and an adult from the Gulf of Mexico; these are referred to *Taractes (Taractes) rubescens*, the *Steinegeria rubescens* of Jordan and Evermann. A synopsis of *Taractes* and an enumeration of the species and principal synonyms are provided.

LITERATURE CITED

Asso y del Rio, Ignacio Jordan de
1801. Introducción á la ichthyología oriental de España. Anales Ciencias Nat., 1801, vol. 4, pp. 28-52. Also separate: Madrid, 1801, 28 pp., 4°, not seen.

Barnard, K. H.
1925- A monograph on the marine fishes of South Africa. Ann. South
1927. African Mus., vol. 21, 1065 pp., 37 pls.
1948. Further notes on South African marine fishes. Ann. South African Mus., vol. 36, pp. 341-406, pls. 9-13.

Berg, Leo S.
1947. Classification of fishes both recent and fossil. 517 pp., Edwards, Ann Arbor.

Bigelow, Henry B. and William C. Schroeder
1929. A rare bramid fish (*Taractes princeps* Johnson) in the northwestern Atlantic. Bull. Mus. Comp. Zoology, Harvard Coll., vol. 69, pp. 41-50, 1 pl.

Bleeker, Pieter
1873. Memoire sur la faune ichthyologique de China. Ned. Tijdschr. Dierk., vol. 4, pp. 113-154.
1876. Systema percarum revisum. Arch. Néerl. Sc. Nat., vol. 11, pp. 289-340.

Bloch, Marc Elieser
1785-1795. Naturgeschichte der ausländischen Fische. 9 pts., 324 pls., Berlin.

Bloch, Marc Elieser and Johann Gottlob Schneider
1801. Systema ichthyologiae . . ., 584 pp., 110 pls., Berlin.

Bory de Saint-Vincent, J. B. G. M.
1823. Dictionnaire classique d'Histoire naturelle, Vol. 3, 593 pp., Paris.

Collin, Jonas
1874. Meddelelse om Brama Raschii Esmark. Forh. Skand. Naturforsk, vol. 11, pp. 418-423.

Cuvier, Georges and Achille Valenciennes
1831. Histoire naturelle des Poissons. Vol. 7, 531 pp.

Esmark, Lauritz
1862. Beskrivelse over en ny fiskeart, *Brama raschii* Esm. Forh. Vidensk. Selsk. Christiania, 1861 (1862), pp. 238-247.
1868. Bidrag til Finmarkens fiskefauna. Forh. Skand. Naturf., Christiania, vol. 10, pp. 516-529.

Fitch, John E.
1953. Extensions to known geographical distributions of some marine fishes on the Pacific coast. California Fish and Game, vol. 39, pp. 539-552.

Fowler, Henry W.
1936. The marine fishes of West Africa, based on the collection of the American Museum Congo Expedition, 1909-1915. Bull. Amer. Mus. Nat. Hist., vol. 70, 1493 pp.
1956. A rare pomfret, *Taractes princeps* (Johnson), on the New Jersey coast. Pp. 1-4, New Jersey State Museum.

Günther, Albert
1860. Catalogue of the acanthopterygian fishes in the collection of the British Museum, Vol. 2, 548 pp., British Museum.

Hilgendorf, Franz
1888. Die Fische der Azoren. *In* Simroth, H. Zur Kenntnisse der Azorenfauna. Archiv. Naturges., 1888, pt. 1, pp. 179-234.

Hutton, Frederick W.
1875. Descriptions of new species of New Zealand fish. Ann. Mag. Nat. Hist., ser. 4, vol. 16, pp. 313-317.
1876. Contributions to the ichthyology of New Zealand. Trans. Proc. New Zealand Inst., vol. 8 (1875), pp. 209-218.

Johnson, James Yate
1863. Descriptions of five new species of fishes obtained at Madeira. Proc. Zool. Soc. London, 1863, pp. 36-46.

Jordan, David Starr and Barton Warren Evermann
1887. Description of six new species of fishes from the Gulf of Mexico, with notes on other species. Proc. U. S. Nat. Mus., vol. 9, pp. 466-476.
1896. The fishes of North and Middle America, a descriptive catalogue of the species of fish-like vertebrates found in the waters of North America, north of the Isthmus of Panama. Bull. U. S. Nat. Mus., no. 47, pt. 1, pp. 1-1240.

Jordan, David Starr, Barton Warren Evermann and Howard Walton Clark
1930. Check list of the fishes and fishlike vertebrates of North and Middle America, north of the northern boundary of Venezuela and Colombia. Rep. U. S. Comm. Fish. 1928, pt. 2, 670 pp.

Jordan, David Starr, and Eric Knight Jordan
1922. A list of the fishes of Hawaii, with notes and descriptions of new species. Mem. Carnegie Mus., vol. 10, no. 1, pp. 1-92, pls. 1-4.

Jordan, David Starr, Shigeho Tanaka, and John Otterbein Snyder
1913. A catalogue of the fishes of Japan. Journ. Coll. Sci., Tokyo Imp. Univ., vol. 33, art. 1, 496 pp.

Lilljeborg, Wilhelm
1884. Sveriges och Norges fiskar. 3 vols., Upsala.

Lowe, R. T.
1843. Notices of fishes newly observed or discovered in Madeira during the years 1840, 1841 and 1842. Proc. Zool. Soc. London, pt. 11, pp. 81-95.
1843-1860. A history of the fishes of Madeira. 196 pp., 27 pls., Quaritch, London.

Lunel, Godefroy
1866. Révision du genre castagnole (*Brama*) et description d'une espèce nouvelle *Brama saussurii*. Mem. Soc. Phys. et Hist. Nat., Geneve, vol. 18, pp. 165-196, pls. 1-2.

Matsubara, Kiyomatsu
1936. A new bramid fish found in Japan. Bull. Japanese Soc. Sci. Fish., vol. 4, no. 5, pp. 297-300.

Maul, G. E.
1954. Monografia dos peixes do Museu Municipal do Funchal — ordem Berycomorphi. Bol. Mus. Munic. Funchal, no. 7, art. 17, pp. 5-41.

Mead, Giles W.
1957. On the bramid fishes of the Gulf of Mexico. Zoologica (N.Y.), vol. 42, pp. 51-61, pls. 1-3.

Poey y Aloy, Felipe
1856-1861. Memorias sobre la historia natural de la isla de Cuba, . . . Vol. 2, 442 pp., 19 pls., Havana.

Rafinesque-Schmaltz, C. S.
1810. Caratteri di alcuni nuovi generi e nuove specie di animali . . . Sicilia. . . . 105 pp., 20 pls., Palermo.

Regan, C. Tate
1911. The anatomy and classification of the teleostean fishes of the orders Berycomorphi and Xenoberyces. Ann. Mag. Nat. Hist., ser. 8, vol. 11, pp. 1-9, pl. 1.

Roule, Louis
1929. Description de poissons abyssaux provenant de l'île Madère et des parages du Maroc. Bull. Inst. Océanog., Monaco, no. 546, 19 pp.

Smitt, F. W. (ed.), B. Fries, C. U. Ekstrom and C. Sundervall
1892-1895. A history of Scandinavian fishes. ed. 2, 1240 pp., 54 pls., Stockholm.

Snyder, John Otterbein
1904. A catalogue of the shore fishes collected by the steamer *Albatross* about the Hawaiian Islands in 1902. Bull. U.S. Fish Comm., vol. 22, pp. 513-538, 13 pls.

Springer, Stewart, and Harvey R. Bullis, Jr.
1956. Collections by the *Oregon* in the Gulf of Mexico. Spec. Sci. Rep. — Fisheries (United States Department of the Interior, Fish and Wildlife Service), no. 196, 134 pp.

STARKS, EDWIN CHAPIN
1904. The osteology of some berycoid fishes. Proc. U. S. Nat. Mus., vol. 27, pp. 601-619.

STEINDACHNER, FRANZ, AND L. DÖDERLEIN
1883. Beiträge zur Kenntnisse der Fische Japans (I). Denkschr. Akad. Wiss. Wien., vol. 47, pp. 211-242, pls. 1-7.
1884. Beiträge zur Kenntnisse der Fische Japans (III). Denkschr. Akad. Wiss. Wien., vol. 49, pp. 171-212, pls. 1-7.

WEBER, MAX, AND L. F. DE BEAUFORT
1936. The fishes of the Indo-Australian Archipelago. Vol. 7, 607 pp., Brill, Leiden.

WHITLEY, GILBERT
1938. Ray's bream and its allies in Australia. Australian Zoologist, vol. 9, pp. 191-194, pl. 19.

	Adult of *Taractes* (*Taractes*) *rubescens* from Gulf of Mexico	Juvenile of *Taractes* (*Taractes*) *rubescens* from Gulf of Mexico (type of *Steinegeria rubescens*)	Juvenile of *Taractes* (*Taractes*) *rubescens* from Gulf of Mexico	Juvenile of *Taractes* (*Taractes*) *rubescens* from off Hawaii	Juvenile of *Taractes* (*Taractes*) *asper* from off Madeira	Juvenile of *Taractes* (*Taractes*) *asper* from off Madeira	Type of *Trachyberyx barretoi* from Roule, 1929:4 (fig.)	Type of *Taractes asper*, from Lowe, 1843:82
Standard length (mm.)	635.0	96.5	54.0	27.5	56.5	113.5	153.0	"Small"
Measurements, in per cent of standard length								
Length of head	30.5	39.4	41.7	49.4	40.0	—	33.7	—
Depth of body at origin of dorsal fin	40.1	50.8	49.1	54.5	45.3	48.0	39.5	—
Least depth of caudal peduncle	6.3	9.3	8.1	9.5	10.0	8.8	9.7	—
Horizontal diam. of eye	6.5	11.9	14.8	18.5	15.9	11.5	11.2	—
Snout to origin of dorsal fin	42.8	47.2	49.1	49.8	46.2	43.6	41.5	—
Snout to origin of anal fin	60.6	—	65.7	71.3	61.9	67.0	57.7	—
Snout to origin of pectoral fin	31.6	37.8	42.6	42.5	37.3	36.6	35.7	—
Length of pectoral fin	37.8	—	38.9	45.8	34.7	—	26.0	—
Length of ventral fin	12.8	27.5	33.3	47.6	36.3	—	22.9	—
Length of longest dorsal ray	27.4	26.9	36.1	44.4	32.7	—	19.4	—
Length of longest anal ray	—	24.9	31.5	44.4	26.5	24.2	21.3	—
Length of mid-caudal ray	9.6	22.3	31.5	43.6	34.5	—	—	—

	Adult of *Taractes* (*Taractes*) *rubescens* from Gulf of Mexico	Juvenile of *Taractes* (*Taractes*) *rubescens* from Gulf of Mexico (type of *Steinegeria rubescens*)	Juvenile of *Taractes* (*Taractes*) *rubescens* from Gulf of Mexico	Juvenile of *Taractes* (*Taractes*) *rubescens* from off Hawaii	Juvenile of *Taractes* (*Taractes*) *asper* from off Madeira	Juvenile of *Taractes* (*Taractes*) *asper* from off Madeira	Type of *Trachyberyx barretoi* from Roule, 1929 :4 (fig.)	Type of *Taractes asper*, from Lowe, 1843 :82
Counts:								
Dorsal fin	31	29½	30½	31½	32½	32	32	33
Anal fin	20½	21½	21½	21	23½	25	25	23
Pectoral fin	20	21	20	21	18	—	20	17
Ventral fin	I-5	I-5	I-5	I-5	I-5	I-5	I-5	I-5
Caudal fin	I-15-I	I-15-I	I-15-I	I-15-I	I-15-I	I-15-I	"19"	4 + VIII 3 + VII
Gill rakers	2+8	2+8	2+9	2+7	2+7	2+7	—	—
Scales in median longitudinal series	49	—	52	48	49	—	49	43[3]
Vertebrae (incl. hypural)	42	42	—	—	—	42	—	—

TABLE 1 — Proportional measurements and counts taken from an adult and three juvenile specimens of *Taractes* (*Taractes*) *rubescens* from the Gulf of Mexico and off Hawaii, two juveniles of *Taractes* (*Taractes*) *asper* from off Madeira, the type specimen of *Trachyberyx barretoi* (from Roule) and that of *Taractes asper* (from Lowe)

[3] If Lowe excluded from his count the scales on the caudal peduncle which merge to form a keel, his enumeration of the scales in a longitudinal series is in accord with our counts of other juvenile Madeiran specimens.

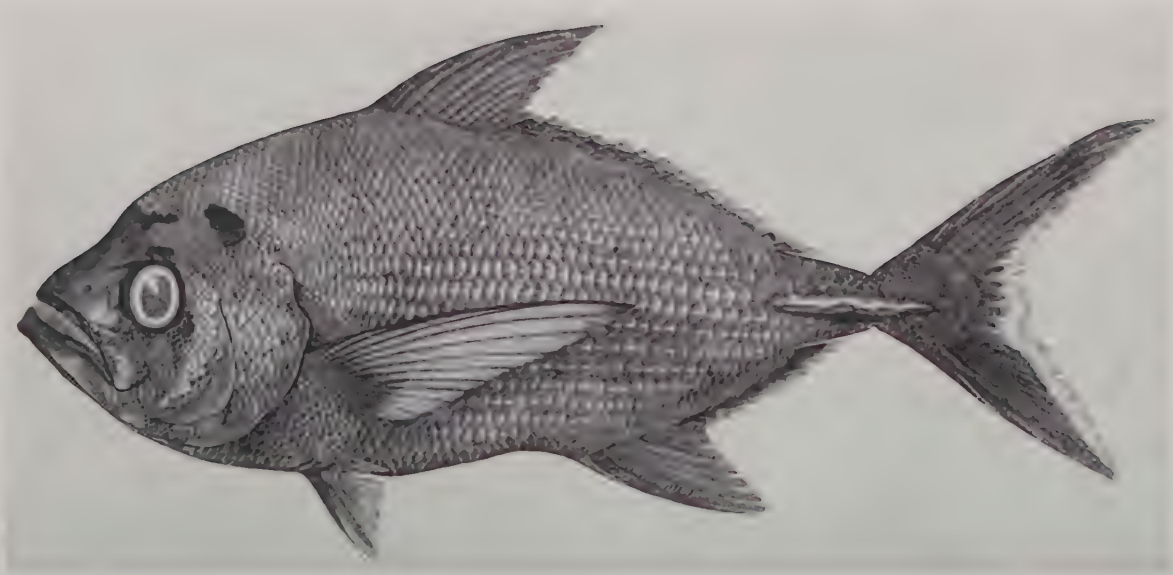

Plate. Adult *Taractes* (*Taractes*) *rubescens*, 635 mm. in standard length, from the Gulf of Mexico. (Drawn by Mildred H. Carrington.)

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NOTES

An Unusually Large Salp

A large example of *Thetys vagina* Tilesius, solitary form, was captured in a 1-meter (mouth diameter) closing-type plankton net at a depth between 120 and 170 meters by the Pacific Oceanic Fishery Investigations, U. S. Fish and Wildlife Service, on February 5, 1956, at 22° 15′N. latitude, 157°46′W. longitude. The specimen measured 306 mm. in length without processes and 333 mm. with processes. By water displacement its total volume equalled 278 ml.

This specimen is apparently larger than any salp previously known and is therefore considered worthy of note. The largest salps previously reported have had lengths as follows: *Thetys vagina*, solitary form, 226 mm. (Traustedt, 1885. *K. Danske Vidensk. Selsk., Skr., Naturv. og. Math. Afd.* 2(8): 337–400 [as *Salpa costata-tilesii*]); *Helicosalpa komaii* (Ihle and Ihle-Landenberg), solitary form, 230 mm. (Komai, 1932. *Kyoto Univ., Col. Sci., Mem.*, Ser. B. 8(1): 65 80 [as *Salpa virgula*]); *Salpa maxima* Forskål, solitary form, 230 mm. (Thompson, 1948. *Pelagic Tunicates of Australia*. Commenwealth Council for Scientific and Industrial Research, Melbourne. 196 pp.). In volume the largest specimen previously reported was a solitary form of *Helicosalpa virgula* (Vogt), 141 mm. in length, which measured 158 ml. in total volume by water displacement (Yount, 1954. *Pacific Sci.* 8(3): 276–330).

The nomenclature used in this note follows that of Yount (*ibid.*).—*Eugene L. Nakamura, Pacific Oceanic Fishery Investigations, U. S. Fish and Wildlife Service, Honolulu, Hawaii, and James L. Yount, Dept. of Biology, University of Florida, Gainesville, Florida.*

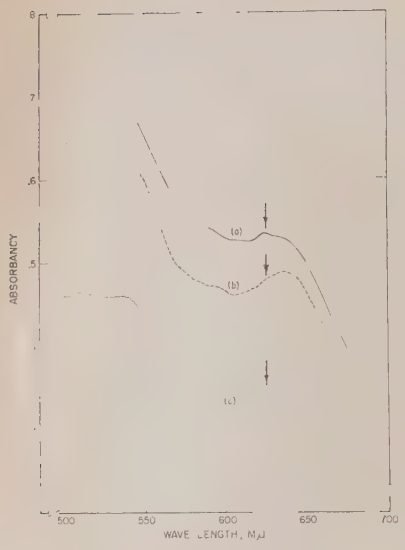

Figure 10. Reflectance curves of acid-acetone – extracted precooked tuna of decreasing greenness

a, b, c. Absorption decrease with decrease in greenness in the 610–620-mμ range

Table II. Fat and Peroxide Values of Raw Tuna Flesh

Samples	Description	Fat, %	Meq. Peroxide/1000 Grams Fat
Green			
1	Green	1.29	40
2	Pale green	0.47	14
3	Slightly green	0.63	24
4	Green	0.82	14
		0.79	12
Very pink			
1	Abnormally pink	0.55	27
2	Abnormally pink	0.92	20
		1.07	40
3	Orange	0.46	26
		0.44	22
Normal and Pale			
1	Normal	0.50	13
2	Washed out	1.57	9
3	Normal	0.59	9
4	Normal	0.58	4
5	Normal	0.54	10
		0.51	8

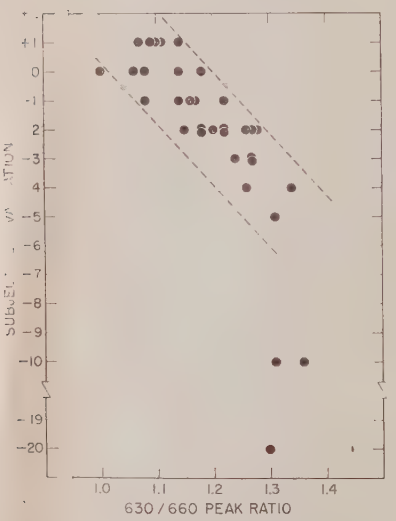

Figure 11. Relationship of methemoglobin content of raw tuna flesh to color rating as subjectively judged

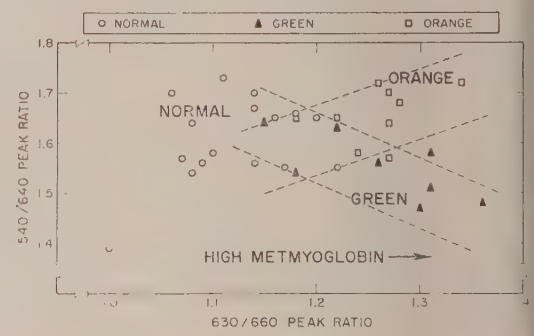

Figure 12. Relationship of methemoglobin content of raw fish flesh to color of meat after precooking as objectively judged (540/640 ratio)

Measurements made from absorption in spectral reflectance

fish caught by the long-line method of fishing.

The theory was tested through the facilities of the Coconut Island Marine Laboratory of the University of Hawaii. A fishing boat was available with a live-well in which it was possible to maintain small tuna alive. In addition, small yellowfin tuna abound in local waters in certain seasons. With the cooperation of the staff of the Hawaii Marine Laboratory, it was possible to catch tuna with lures and to kill certain of these within a few minutes of capture while maintaining others in a wounded and dying condition for many hours in the live well. The latter were finally killed and the flesh of both types was analyzed for methemoglobin by the reflectance technique. Two sets of such paired samples were obtained. Differences in methemoglobin

Acknowledgment

The authors wish to thank Albert L. Tester, and other staff members of the Pacific Oceanic Fishery Investigations for suggestions and help. Thanks are also due to Fred Jermann, food technologist of the Hawaiian Tuna Packers, for help in the processing and evaluation of the fish and to the staff of the Hawaiian Marine Laboratory for catching and treating tuna in local waters.

Literature Cited

(1) Austin, J. H., Drabkin, D. L., *J. Biol. Chem.* **112,** 67 (1935).
(2) Bowen, W. J., *Ibid.*, **179,** 235 (1949).
(3) Brooks, J., *Proc. Roy. Soc.* (*London*) **118B,** 560 (1935).
(4) Brown, D. W., Tappel, A. L., *Food Research* **22,** 214 (1957).
(5) Brown, D. W., Tappel, A. L., Olcott, H. S., *Ibid.*, **23,** 262 (1958).
(6) Erdman, A. M., Watts, B. M., J. Agr. Food Chem. **5,** 453 (1957).
(7) Fox, D. L., Millott, M., *Experientia* **10,** 185 (1954).
(8) Fox, J. B., Schweigert, B. S., Abstracts of Papers, p. 64C, 132nd Meeting, ACS, New York, Sept. 1957.
(9) Ginger, I. D., Lewis, V. J., Schweigert, B. S., J. Agr. Food Chem. **3,** 156 (1955).
(10) Ginger, I. D., Wilson, G. D., (12) Lemberg, R., Legge, J. W., "Hematin Compounds and Bile Pigments," Interscience, New York, 1949.
(13) Lewis, V. J., *J. Biol. Chem.* **206,** 109 (1954).
(14) Matsuura, F., Hashimoto, K., *Bull. Japan. Soc. Sci. Fisheries* **20,** 308 (1954).
(15) Matsuzaka, Y., Takahashi, N., private communication.
(16) Miyauchi, D. T., *U. S. Fish Wildlife Serv., Com. Fish. Rev.* **12(10),** 1 (1950).
(17) Morgan, V. E., *J. Biol. Chem.* **112,** 557 (1936).
(18) Naughton, J. J., Frodyma, M. M., Zeitlin, H., *Science* **125,** 121 (1957).
(19) Naughton, J. J., Frodyma, M. M., Zeitlin, H., U. S. Fish and Wildlife Service, Spec. Sci. Rept., *Fisheries Ser.*, No. **247** (1957).
(20) Rossi-Fanelli, A., Antonini, E., *Arch. Biochem. and Biophys.* **58,** 498 (1955).
(21) Shorland, F. B., *Australian J. Sci.* **18(4A),** 49 (1956).
(22) Sperry, W. M., "Methods of Biochemical Analysis," vol. 2, pp. 83–112, Interscience, New York, 1955.
(23) Tixier, R., *Ann. inst. océanog.* (*Paris*) **22,** 343 (1945).
(24) Watts, B. M., *Advances in Food Research* **5,** 1–52 (1954).

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elationship between Rate of hotosynthesis and Growth of uvenile Red Salmon

Bare Lake, a 120-acre unstratified lake
i Kodiak Island, Alaska, was fertilized
nnually during the period 1950–56 with
organic nitrate and phosphate fertiliz-
s. The total amount of fertilizer added
ch year was calculated to increase the
ncentration of phosphate phosphorus
d nitrate nitrogen by approximately
05 and 0.25 mg/liter, respectively.

The purpose of fertilization was to
etermine whether this process will
ring about an increase in the food sup-
y of red salmon (*Oncorhynchus nerka*)
uring their lake residence, and thereby
crease their growth and survival rate
ior to their migration to sea, which
ay occur during the beginning of their
cond, third, or fourth year of age.
udies have demonstrated that fertiliza-
n during the years 1950–53 increased
e rate of photosynthesis of the phyto-
ankton and increased phytoplankton
oduction (*1*).

Phytoplankton are utilized by a variety
benthic insect larvae and zooplankton
on which the fish have been observed
feed. That these organisms have in-
eased in production is strongly sug-
sted by the fact that growth of young
d salmon has increased since 1950
Fig. 1*a*). The seaward-migrating red
lmon, generally referred to as smolts,
ceived no benefit from this fertiliza-
n in 1950, for they migrated prior to
e July application and the juveniles
uring their first growing season prob-
ly received very little benefit by 27
ugust, the date their growth was cal-
ulated.

To obtain information about the size
red salmon smolts prior to 1950, meas-
rements of scale radii were taken of
nolt scales for the years 1950–53 and
the fresh-water zone scales from adult
lmon that returned to the lake from
ie smolt migrations of 1947 through
953. A significant correlation was found
etween the scale radii and fork length
smolts, and it was found that the
esh-water zone scale radii of adult red
lmon were equal to or greater than
ale radii measurements from samples
the smolts producing the adults. Since
ie scale radii of adult red salmon re-
rning from the smolt migrations of
947–49 were slightly smaller than those
eturning from the smolt migration of
950, this is good evidence that the
nolts of those years were no larger than
ose of 1950.

Thus, it appears that fertilization has

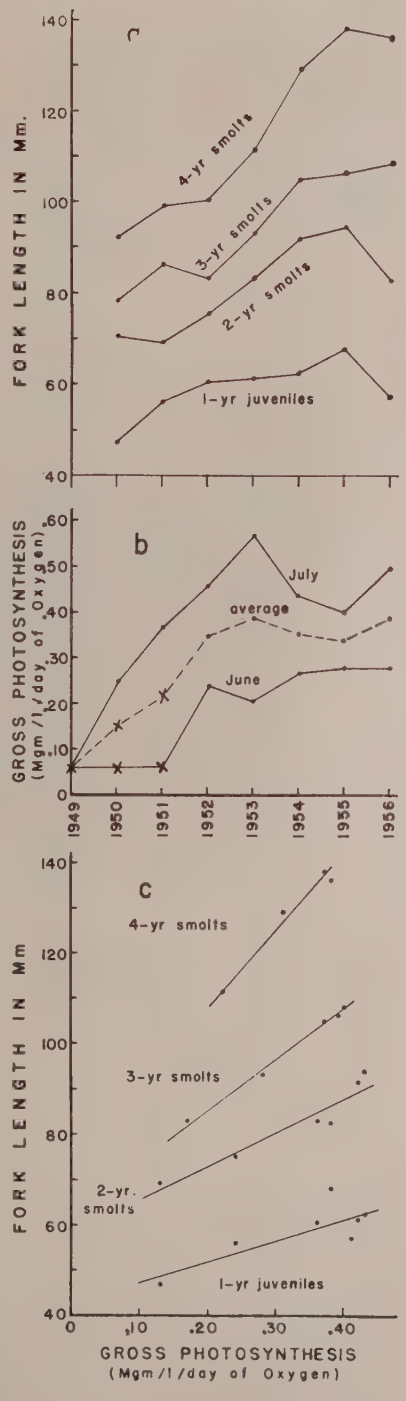

Fig. 1. (*a*) Curves showing the mean length of juvenile red salmon on 27 August of their first growing season and of red salmon smolts migrating to sea in the beginning of their 2nd, 3rd, and 4th year of life for the years 1950–56. (*b*) Curves showing the mean rate of gross photosynthesis during the years 1949–56 for the 40-day periods following the June and July fertilization. Also presented is a curve of the average of the two periods. Points on the curves marked by x's denote the values are estimated or partly estimated. (*c*) Scatter diagrams showing the relation between gross photosynthesis and fork length for each age group of fish. Regression lines are drawn by inspection.

brought about an increment in fish growth that has to date been rather progressive over the years. It is important to note that during the period no increase in growth of red salmon occurred in nearby unfertilized Karluk Lake. Because of the long life cycle of red salmon, data are not yet sufficient to demonstrate whether fertilization has increased the fresh-water survival.

The rate of growth of fish is very sensitive to influence by the food supply. Although plankton and bottom fauna have been sampled regularly, the time-consuming censuses have not yet been completed. However, data are available on the primary productivity as measured by the rate of photosynthesis of the phytoplankton (Fig. 1*b*). These measurements were made by the method originally described by Gaarder and Gran (*2*).

No actual determinations of photosynthesis were made in 1949, but a few determinations were made prior to the July fertilizations of 1950 and 1951, years when the lake was not fertilized in June. On the basis of measurements made during those periods (*1*), it is believed the mean rate of oxygen production would not have exceeded 0.12 mg/liter per day and may well have been about 0.06; the latter figure is plotted as the rate during 1949 and during June of 1950 and 1951. Following the 1951 season the same amount of fertilizer was used as before, but it was applied during two periods, June and mid-July.

A cursory comparison of the curves of seasonal rate of photosynthesis and size of fish reveals a certain correspondence between them (Fig. 1*a* and *b*). To show the relation more clearly, diagrams were made (Fig. 1*c*). It was thought that three periods in time would be of importance in affecting the population size and growth of the new crop of insect larvae hatching in early summer and which would be fed upon by the young juvenile red salmon that had hatched earlier that spring. The period following July fertilization of the year prior was considered important to the survival of the brood stock of insect larvae which was to produce the new generation to be utilized by the fish. Periods following both the June and July fertilizations would influence the growth and survival of the newly hatched larvae. Thus, in

Fig. 1*c* the length the first-year juvenile salmon attained each year is plotted against the mean rate of photosynthesis after the June and July fertilizations of that year and the period following the July fertilization of the preceding year. All three periods were weighted equally in establishing the mean. In a somewhat similar manner, smolt size was plotted against the mean rate of photosynthesis over those periods mostly responsible for the development of insect larvae upon which the fish feed during their lake residence.

It might be supposed, since so many steps exist between the original synthesis of food materials by the phytoplankton and growth of fish, and since fish are affected by so many environmental factors in addition to food supply, that a significant correlation would not exist. Nevertheless, the growth of smolts showed a very close relation with the rate of photosynthesis (Fig. 1*c*). The relationship with juveniles at the end of their first growing season is weaker. However, the figures indicate a much closer relation between fish growth and primary photosynthetic productivity than might have been expected a priori (*3*).

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References and Notes

1. P. R. Nelson and W. T. Edmondson, *U.S. Fish Wildlife Serv. Fishery Bull. No. 102* (1955).
2. T. Gaarder and H. H. Gran, *Rappt. et proc Conseil Intern. Explor. Mer* **42** (1927).
3. A more detailed account of the effects of fertilizing Bare Lake on the red salmon population is in press (*U.S. Fish Wildlife Serv. Fishery Bull.*).

18 March 1958

AGE DETERMINATION OF ALBACORE BY THE VERTEBRAL METHOD

by
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ABSTRACT

An attempt was made to determine the age of central North Pacific and Hawaiian Albacore, *Germo alalunga* (Bonnaterre), by counting rings in the vertebral centra, a method for which some degree of success had been reported elsewhere. Results were negative because of the impossibility of duplicating counts in successive readings or by different readers. It is concluded that the Albacore from these areas cannot be aged by the vertebral method with presently existing techniques.

INTRODUCTION

This is a preliminary report on a study to determine the age and growth of Albacore, *Germo alalunga* (Bonnaterre), taken from the waters of the Hawaiian Islands and from the central Pacific Ocean north and northwest of Hawaii. This study is part of the Albacore research program presently being conducted by the Pacific Oceanic Fishery Investigations (POFI) of the U.S. Fish and Wildlife Service under Public Laws 329 (80th Congress) and 537 (Saltonstall-Kennedy Act, 82nd Congress).

Several workers in the past have reported on the age and growth of Albacore as determined by examination of the surface marking on the vertebral centra. Aikawa and Kato (1938) based their studies on 10 large Albacore taken near Midway Islands and five small fish taken off northeastern Japan. Partlo (1955) made a more comprehensive study based on vertebrae of 1,000 fish taken during the 1950 fishing season in the offshore waters of California, Oregon, Washington, and British Columbia. Figueras (1955) followed with a brief report based on 100 specimens taken off the coast of Galicia (northwestern Spain). Uno (1936a, b), without giving details of his technique, reported on the results of his study based on about a thousand fish taken off the Japanese coast.

All of these workers either directly or indirectly suggested the presence of rings on the inner surfaces of the two hollow cones of the amphicoelous Albacore vertebra. They concluded that each ring represented an annulus and therefore, the number of rings was an indicator of age. By measuring the distance from the centre of the centrum to each ring, they believed they were deriving an estimate of the growth of the fish. Aikawa and Kato, Figueras, and Uno, as far as we can determine, have provided no evidence showing that the rings on the vertebrae are indeed "age rings" and annual in nature. Partlo hypothesized that the rings are true year marks by the following: (1) by assuming that the length groups in the size frequencies are age groups, he found that there was acceptable agreement between the mean length of fish assigned to each vertebral ring-class and the mean length of corresponding length-groups in the sample, and (2) there was agreement between the lengths of young fish calculated from vertebral measurements of older fish and the observed lengths of young fish. For the latter, Partlo, working with a subsample of 98 fish, found that the observed lengths were consistently greater than the calculated lengths because the fish were captured some time after the last ring was formed. Partlo concluded that "from the above it seems clear that the third and subseguent vertebral rings are produced annually. It is assumed, in the absence of contrary evidence, that the inner two rings are annual also."

In our study we attempted to evaluate the use of vertebrae to determine the age of Albacore taken in the North Pacific and in Hawaiian waters. Employing a wider size range of fish than had hitherto been used by any single worker, we hoped to extend previous findings to include the large fish landed in the Hawaiian Islands, and at the same time make a careful examination of the evidence appearing to indicate that the rings on the centra are true year marks. However, as will be shown, we were not able to duplicate or verify past results, nor did we find that we could use the vertebrae to age central North Pacific and

. *Indo—Pacific Fish. Coun.*, **7** (II—III): 49—52, 1957.

Hawaiian Albacore. The results of our study, though largely negative, be presented for the infomation of those who are presently engaged in similar studies and for others who may work on this problem in the future.

MATERIALS AND METHODS

While most of the past investigators used thoracic vertebrae for Albacore age determination, we selected the 15th and 16th caudal vertebrae. Our choice of the caudal vertebrae was based chiefly on accessibility, or the ease with which they could be acquired in the field or at the local fish markets. Furthermore, correspondence with other investigators engaged in similar studies indicated that caudal vertebrae showed as much promise as any other. Subsequent examination of each of the 38 vertebrae of an Albacore revealed no notable differences in the appearance of the concentric markings.

Our sample, collected between January 1955 and July 1956, consisted of vertebrae from 212 Hawaiian and 53 central North Pacific Albacore. The Hawaiian Albacore, taken by the longline fishery, were generally large, ranging in size from 93 to 128 cm. (33 to 93 pounds), while the central North Pacific albacore, taken by trolling, gill net, and longline, were smaller, ranging between 51 and 112 cm. (6 to 65 pounds).

The vertebrae were sectioned and prepared for examination according to the method described by Partlo. The cleaned and dried vertebra was cut longitudinally along the dorsoventral plane, but to one side of the median line, into two unequal parts. The larger of the two parts was then sanded down until the centre of the centrum was exposed. Additional cleaning and accentuating of the concentric rings were done by immersing the vertebrae in a one-percent solution of potassium hydroxide for 48 hours ; this was followed by preservation in 95-percent alcohol.

The Albacore vertebra is amphicoelous, or concave at both ends of the centrum. A sectioned vertebra reveals two cones whose vertices meet at or near the centre of the centrum with the bases forming the margins of the vertebra. On the inner surface of these cones are concentric rings running parallel to the outer margin of the centrum. These rings were described by Partlo as "narrow translucent zones separated by broad opaque zones similar to those described by Freidenfelt (1922) *Lucioperca*. In the Albacore the narrow zo were observed not only as translucent ba but also as eruptions or ridges on the centr surface. The innermost ring differed sligh from the others but was nevertheless cle marked." In the course of our study we fo that certain rings do appear as definite rid on the surface, while others appear as narr translucent bands without any surface erupti and still others are more suggestions of li or bands. In addition to examining the v tebrae under natural and incandescent lig we experimented with polarized and vario coloured lights but without achieving appreciable improvement in the appearance the rings. Various types of stains were tri but here again the results were disappointi from the standpoint of improving the "rea bility" of the rings.

CHANGE IN SHAPE OF VERTEBRAE WI GROWTH OF FISH

In the course of examining a wide ser of vertebrae, we observed that while the t cones of a caudal vertebra are nearly the sa size in small fish, the posterior cone appear larger than the anterior among large fish, i dicating that the vertebra changes its sha with growth of the fish. The lengths of t two cones were measured and the ratio of t two measurements was plotted against the si of the fish (Fig. 1). While the ratio is near 1 : 1 in the smallest vertebrae examined (fi of around 50 to 60 cm. in length), the posteri cone is definitely larger than the anterior the larger vertebrae. This changing proporti is described by the rectilinear regression :

$$\hat{Y} = 0.9229 + 0.0019\ L$$

where $\hat{Y}$ is the ratio of the two cones a L is the fork length in centimeters. Althou the two cones of a caudal vertebra grow di proportionately, each cone in itself exhibits linear growth with growth of the fish. Th in working with a wide size range of caud vertebrae, it is important that any measuremer of ring or vertebral radii to estimate grow increments of the fish should be confin to either the anterior or the posterior con and not to averages of the two.

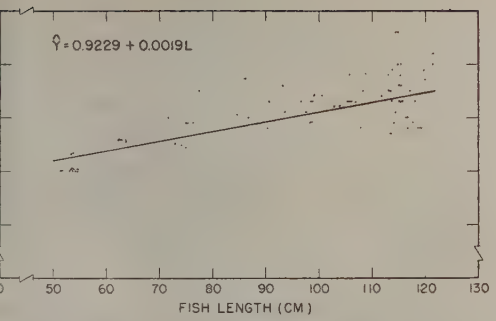

Fig. 1. Ratio of the average length of the rior and anterior cones plotted against fish to demonstrate the disproportionate growth e two cones of the amphicoelous vertebrae bacore.

READIBILITY OF VERTEBRAL RINGS

After deciding upon the criteria to be follow- he authors started on a series of indepen- ring counts and ring-radii measurements. tal of nine series of counts and measure- s resulted in agreements between any series of as low as eight percent and only gh as 45 percent. There was poor agree- not only between counts of the two rs but also between counts made by the person. Consistency was often not achi- even between counts of the anterior and rior cones of the same vertebra. While most e disagreement was by one ring (31 to 50 nt), discrepancies of as many as four rings red in many of the comparisons. Thus, ound that we could not sātisfactorily dup- e ring counts and therefore could not meet irst prerequisite to the use of vertebrae ging Albacore. Our findings are in contrast rtlo's, who reported that "counts of rings reproducible with high consistency."

We observed that much of the inconsis- in the counts could be attributed to the ulty of distinguishing rings near the ver- f the cone and also at the margin. This not mean, however, that the rings on the al portion of the cones were clear and distinguishable, because here also many onstencies resulted.

SAMPLES FROM SMALL FISH

Age determination by means of hard parts frequently becomes more difficult and the method often breaks down completely in older fish. Since other investigators dealt largely with small fish, we concentrated our efforts on a group of similarly small fish (less than 90 cm.) in order to determine whether or not our difficulties were due to the use of larger, older fish. In one test consisting of two series of counts, we found that there was a 56 per cent agreement for fish less than 90 centimetres as compared with 30 per cent for those of larger size. The higher agreement with smaller fish is, of course, to be expected because of the fewer growth rings involved. After several more tests with series of small fish, we concluded that the counts were still far too variable to be acceptable as indicators of age.

DISCUSSION

A serious problem, especially in working with samples of small vertebrae, is to be strictly objective in making ring counts or measurements. Since there is a linear relationship between the vertebral radius and the body length of Albacore, it is almost impossible to make a reading without first forming an opinion as to how many rings a certain-sized vertebra should have. Because of the great variability in the appearance of the rings, we found it difficult to follow the criteria which we had established for judging the vertebrae. In retrospect, it may perhaps be said that our main difficulty was not so much in not being able to follow any set of criteria as not being able to develop acceptable criteria because of the variability of the rings. However stated, subjectivity was inadvertently introduced into our readings, particularly when we attempted to duplicate previous findings. This can be illustrated with an example: If the investigator measures the radius of the second ring at 5 mm. in a particular vertebra, and if all previous second-ring radii have fallen between 3 and 4 mm., he inadvertently looks closer at the vertebra for a second ring which he may have "missed". More often than not he will "find" the "missing" ring. In fact, we could locate "rings" almost anywhere on the centrum if we looked closely enough. While we could eliminate bias to a large degree when making counts, it was much more difficult to do so in the case of measurements.

CONCLUSIONS

Although vertebrae of small Albacore were somewhat more "readable" than those of the larger Albacore, we were unable to achieve sufficient consistency in our readings and measurements to validate this method of age determination. It appears that the Hawaiian Islands and central North Pacific Albacore cannot be aged by the vertebral method with presently existing techniques.

REFERENCES

AIKAWA, H., and M. Kato (1938). Age determination of fish—I. *Bull. Jap. Soc. Sci. Fish.*, **7** (1): 79-88. (English translation—*U. S. Fish and Wildlife Service, Spec. Sci. Rept.—Fisheries*, No. **21**)

FIGUERAS, A. (1955). Renseignement sur l'[illegible] et la croissance du Germo (*Germo alalu* Gmelin). *Council Meeting, Internatio Council for the Exploration of the S Committee on Scombriform Fishes*, No. **24**, (Mimeographed).

PARTLO, J. M. (1955). Distribution, age a growth of eastern Pacific albacore (*Thun alalunga* Gmelin). *Fish. Res. Bd. Canada.*, (1): 35-60.

UNO, M. (1936 a.) *Germo germo* (Lacépède) the waters east of Nojima Promontory, Ti Prefecture (Preliminary Report I). *Bull. J Soc. Sci. Fish.*, **4** (5): 307-309.

———(1936b.) *Germo germo* (Lacépède) the waters east of Nojima Promonto Tiba Prefecture (Preliminary Report I *Bull. Jap. Soc. Sci. Fish.*, **5** (4): 235.

FISHERY MANAGEMENT PROBLEMS AND POSSIBILITIES ON LARGE SOUTHEASTERN RESERVOIRS

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ABSTRACT

Principal problems concerning the fisheries of large reservoirs in the Southeast are: inefficient and highly selective exploitation of fish stocks, and protection and reclamation of damaged or threatened fisheries in tailwaters and tributary streams. Seven mainstream reservoirs on which data are available support an average angling pressure of 4.9 trips per acre per year and an average catch of 16 pounds of sport fish and 6 pounds of food fish. Commercial take is 7 pounds per acre. The rate of catch of sport fish, based upon tag returns, is only 3 percent. Sixteen storage reservoirs support an average angling pressure of 5.0 trips per acre per year and an average catch of 13 pounds of sport fish and 1 pound of food fish. Commercial catch is of no significance. Average rate of catch of sport fish is 17 percent of the catchable population. Fish population studies indicate that there are twice as many sport fish and four times as many food fish in mainstream than there are in storage reservoirs.

Some reservoirs produce harmful effects downstream. Discharges of cold water may seriously reduce fishery values in tailwaters and downstream impoundments. Furthermore, migration of non-sport fish from reservoirs into tributary streams may reduce fishery values there.

In recognition of these problems, the development and application of sound management procedures may be accomplished by controlling species composition and availability of fish through water level control, timber clearing, application of selective toxicants, commercial fishing, introduction of new fish species, and the management of tailwaters and tributaries. Extended research and interagency cooperation are necessary to properly develop and apply sound management. Promotion of angling and regulation of the fishery may best be realized by providing adequate fishing facilities, elimination of certain restricted areas, and in some cases revision of laws and regulations. Biologists must not only meet the present demands for improved sport fishing but must also balance fish yield by increasing the use of food fish by sport and commercial operations.

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Introduction

The demands for flood control, hydroelectric power, and navigation have led to the construction of many reservoirs in the southeastern United States.[2] There are presently 86 large[3] reservoirs totalling more than 2 million acres in this area (Thomas and Harbuck, 1956). The rate of construction is indicated by the 71-percent increase in their number since 1947. The U. S. Army Corps of Engineers water-control program and applications to the Federal Power Commission by private power companies for licenses to construct dams point toward a continued high rate of construction.

The creation of fishery values was not an important consideration in the construction of these impoundments. They have, nevertheless, provided extensive new fishing areas, the values of which have far outweighed the injury to or destruction of a few cherished old ones. Not only has sport fishing become popular with local inhabitants; the tourist trade has added enormously to the economic welfare of the region.

The management of these new fisheries and the lessening of loss from injury to old ones offer numerous and peculiar problems. Difficulties are rendered more severe by a number of special circumstances. Construction of these reservoirs created not only new fisheries but also new and special

[2] Here considered to include the States of Maryland, Virginia, Kentucky, Tennessee, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, and Arkansas.

[3] In this paper only those impoundments with a maximum surface area of at least 1,000 acres are considered. Lowhead reservoirs of Florida and Louisiana, which are actually stabilized lakes, are excluded.

types of environment about which little was known. Fishery biologists and administrators thus have been without the backlog of scientific literature and administrative precedent that usually can assist so greatly in the establishment of a new program. Rather, they have had deliberately to ignore much that has been learned in other areas and embark on a pioneer program of their own. This venture had to be started with the limited, sometimes ill-trained, and always underpaid staffs characteristic of areas in which fishing previously had been of small consequence, and in which management consisted entirely of enforcement of laws that had little rational basis. It is not surprising that early advances in the understanding of reservoir fisheries were slow and halting. It is gratifying that such fine progress has been made and that the outlook for the future is good.

Even though accomplishments to date are trivial in comparison to that which remains to be done, much has been learned about research and management on reservoirs of the Southeast. It appears timely now to undertake an appraisal of the situation—to review progress up to this time and to speculate as to the implications for the planning of future activities.

Fishes of Southeastern Reservoirs

In later discussions references are made repeatedly to certain species and groups of species. To make certain the identity of the fishes and define arbitrary groupings that are employed, the following list of common and scientific names of the principal fishes has been prepared.

SPORT FISH (GAME FISH)

Largemouth bass	*Micropterus salmoides*
Smallmouth bass	*Micropterus dolomieu*
Spotted bass	*Micropterus punctulatus*
Walleye	*Stizostedion vitreum*
Sauger	*Stizostedion canadense*
Striped bass	*Roccus saxatilis*
White bass	*Roccus chrysops*
Muskellunge	*Esox masquinongy*
Rainbow trout	*Salmo gairdneri*

SPORT FISH (PAN FISH)

Black crappie	*Pomoxis nigromaculatus*
White crappie	*Pomoxis annularis*
Rock bass	*Ambloplites rupestris*
Bluegill	*Lepomis macrochirus*
Longear sunfish	*Lepomis megalotis*
Warmouth	*Chaenobryttus coronarius*

FOOD FISH

Carp	*Cyprinus carpio*
Smallmouth buffalo	*Ictiobus bubalus*
Bigmouth buffalo	*Ictiobus cyprinella*

Channel catfish	*Ictalurus punctatus*
Blue catfish	*Ictalurus furcatus*
White catfish	*Ictalurus catus*
Flathead catfish	*Pilodictis olivaris*
Paddlefish	*Polyodon spathula*
Sturgeon	*Acipenser fulvescens*
Fresh-water drum	*Aplodinotus grunniens*
Redhorse	*Moxostoma spp.*
Bullhead	*Ictalurus spp.*

FORAGE FISH

Gizzard shad	*Dorosoma cepedianum*
Threadfin shad	*Signalosa petenensis*

OTHER SPECIES

Skipjack	*Alosa chrysochloris*
Longnose gar	*Lepisosteus osseus*
Mooneye	*Hiodon tergisus*
Goldeye	*Hiodon alosoides*

Types of Impoundments

Reservoirs in the Southeast are generally classified into four groups according to their principal use or location — flood control, power, storage, and mainstream reservoirs. Although most, other than flood control reservoirs, are in fact multiple-purpose impoundments, this partly-arbitrary classification adds considerably in the understanding of the variety of impoundments. In the consideration of fishery problems, all reservoir groups other than mainstream reservoirs may be combined and are referred to in the text as storage reservoirs.

FLOOD-CONTROL RESERVOIRS

The Southeast has seven single-purpose flood-control reservoirs with a total area of 217,000 acres (Table 1). Their average area is 31,000 acres and the mean depth is 22 feet. Surface area, however, is usually about ¼ to ½ of maximum during much of the major fishing period. All of these reservoirs are located on relatively small streams and they may be drawn down to 7 percent of their maximum capacity. Water levels are highest during months of heavy rain, February through May, and are lowest in September and October.

Water is discharged through conduits near the bottom of the reservoir; rarely does water pour over the spillway. The reservoirs may be turbid during the rainy season but usually they are clear (turbidity less than 10 p.p.m.).

TABLE 1.—*Physical descriptions of four types of southeastern reservoirs over 1,000 acres in area.*

Item	Type of reservoir			
	Flood-control	Power	Storage	Mainstream
Number	7	43	22	14
Surface area (acres)[1]				
Combined reservoirs	217,000	300,000	681,000	811,000
Largest reservoir	64,000	38,000	71,000	261,000
Average area	31,000	7,000	31,000	58,000
Mean depth (feet)	22	31	57	20
Percentage of water volume in dead storage[2]	7	40	30	61

[1]Acreages and depths based upon spillway pool levels.
[2]Based upon absolute minimum water levels.

POWER RESERVOIRS

The 43 southeastern power reservoirs at spillway level have a total of 300,000 acres. The average area is 7,000 acres and the mean depth is 31 feet. These reservoirs are located mostly on tributary streams. Water levels are usually highest in late winter and early spring. They are not lowered excessively at other times because of the need for sufficient head to generate electricity efficiently. On occasion these reservoirs may be drawn down to about 40 percent of maximum capacity.

Water is drawn through turbines at the base of the dams. Surplus water frequently passes over the spillway for short periods during rainy seasons. Reservoir waters are usually clear except after heavy rains.

STORAGE RESERVOIRS

The 22 storage reservoirs at spillway level have a total area of 681,000 acres. The average reservoir area is 31,000 acres and the mean depth is 57 feet. Primary purposes of these reservoirs are flood control and power. Water levels are high in the spring and low in the fall. Volume may be reduced to about 30 percent of maximum.

Water is drawn through turbines at the base of the dam and rarely passes over the spillway. Reservoirs of this type are usually clear except immediately following heavy rains.

MAINSTREAM RESERVOIRS

The 14 mainstream reservoirs at spillway level have a total area of 811,000 acres. The average reservoir area is 58,000 acres and the mean depth is 20 feet. They are used primarily for navigation, flood control, and power.

All are located on large rivers.

Except during flood periods or extreme draughts water levels remain relatively stable. Volume may be reduced to about 60 percent of maximum during operations.

Water is drawn through turbines at the base of the dams or through locks for navigation. Large volumes usually flow over the spillways during the late winter and spring. Reservoir waters may be relatively turbid for several months.

Principal differences among the types of reservoirs other than those already listed are: the relatively greater rate of flow through the mainstream reservoirs; construction of mainstream reservoirs in series to facilitate navigation (particularly on the Cumberland and Tennessee Rivers); thermal stratification to a much greater extent in storage and power reservoirs than in other types (Wiebe, 1940); limited shoreline development in mainstream impoundments (49 acres of water per mile of shoreline in mainstream reservoirs, 65 acres per mile in storage reservoirs).

Major Problems of Reservoir Fisheries

The correction of the presently inefficient and highly selective exploitation of fish stocks in the reservoirs proper and the protection and reclamation of damaged or threatened fisheries in tailwaters and tributary streams offer the two most immediate and pressing problems in the development of a research and management program in the Southeast. Other problems exist, to be sure—some of them are mentioned in later discussions—but any long-term programs directed toward the development of truly scientific management must be concentrated on these two.

Fish production of reservoirs in relation to stock

Fish population studies although individually subject to bias, collectively offer useful indices to population composition. Stocks of the southeastern reservoirs have been sampled with gill and trammel nets, seines, various types of traps, and with the use of rotenone. Since the latter appears to be the most dependable single method and one in which sampling errors are generally comparable between reservoirs, records of fish populations were determined from collections by this method. The pounds of fish recovered per acre do not, however, necessarily represent standing crops; efficiency of recovery varies according to local circumstances.

The average recoveries of 146 and 354 pounds of fish per acre from storage and mainstream reservoirs, respectively, suggest that the latter are by far the more productive of fish (Table 2). Sport fish are about 2½ times more abundant in mainstream reservoirs than in storage reservoirs and food fish about four times more abundant. The percentage of weight of large fish was determined in two storage reservoirs where 42 percent

of the weight of sport fish sampled and 73 percent of the food fish were of angling size.[4]

TABLE 2.—*A comparison of average fish population composition and fish catch from 6 mainstream and 9 storage reservoirs in the Southeast*[1]

Item	Type of reservoir	
	Storage[2]	Mainstream
Pounds of fish per acre sampled	146	354
Percentage of fish composition by weight		
Sport	23	24
Food	26	40
Forage	41	25
Other	10	11
Angling catch (pounds) per acre per year		
Sport	13	16
Food	1	6
Commercial take (pounds per acre per year)	...	7
Total pounds of fish taken per acre per year	14	29

[1]Data from: Carter (1954, 1955, 1957); F-2-R Job Completion Report, Tennessee Game and Fish Commission, unpublished; Fetterolf (1955); Swingle (1954); Eschmeyer, Manges, and Haslbauer (1946); Tarzwell (1941, 1945); Eschmeyer and Tarzwell (1941); Chance and Miller (1952).
[2]Includes storage, flood control, and power reservoirs.

Rates of exploitation in the two groups of reservoirs are decidedly unequal. The annual removal of 13 and 16 pounds of sport fish per acre from storage and mainstream reservoirs, respectively, indicates that sport fish are utilized to a greater extent in storage reservoirs. Food fish in storage reservoirs add 1 pound of fish per acre yearly to the catch by angling. Since commercial fishing is usually prohibited, greatly restricted, or inefficient, this fishery makes only a small contribution to the total take of fish.

On mainstream reservoirs food fish add 6 pounds of fish per acre yearly to the catch of anglers, and provide the entire 7 pounds per acre of commercial catch. This total of 13 pounds of fish accounts for most of the 15-pound difference in the annual fish yield per acre between the two types of reservoirs (Table 2).

Fishing pressure was similar on the two groups of reservoirs 5.0 and 4.9 fishing trips per acre annually (Table 3). The average weight of fish per trip was 2.8 from storage and 4.4 pounds from mainstream reservoirs.

The rate of cropping as indicated by returns of tagged sport fish (principally the black basses and black and white crappie) was 17 percent of the

[4] F-2-R, Job Completion Report, Tennessee Game and Fish Commission, unpublished.

catchable-sized fish on storage reservoirs and only 3 percent on mainstream reservoirs. These rates give further evidence of low level of exploitation of sport fish in mainstream impoundments.

TABLE 3.—*Comparison of sport fisheries on 6 mainstream and 11 storage reservoirs in the Southeast*[1]

Item	Type of reservoir	
	Storage[2]	Mainstream
Fishing trips per acre per year	5.0	4.9
Pounds of fish per trip	2.8	4.4
Average weight of each fish (pounds)	0.8	0.9
Yearly removal of fish (pounds per acre)	14	22
Rate of cropping[3]	17	3

[1]Based upon studies by Elser and Van Deusen (1954); Fetterolf (1955); Tarzwell (1945); Eschmeyer, Manges, and Haslbauer (1946); Carter (1954, 1955, 1957); Eschmeyer and Tarzwell (1941); Tarzwell (1941); Chance (1955); Miller (1951); Manges (1950); F-2-R Job Completion Report, Tennessee Game and Fish Commission, unpublished.
[2]Includes storage, flood-control, and power reservoirs.
[3]Percentage returns of tagged fish of catchable size.

The smallmouth, largemouth, and spotted basses represent about 47 percent of the fish taken by angling from storage reservoirs (Table 4). The annual rate of cropping of these fish was 30 percent. This finding proves that angling on storage reservoirs is highly selective. Black and white crappie represented 27 percent of the fish catch and the rate of cropping was 20 percent. The black basses, although the most abundant group of fish in catches from mainstream reservoirs represented only 13 percent of the angling catch, and the rate of cropping was 15 percent. Crappie represented 24 percent of the catch and the rate of cropping was 11 percent.

TABLE 4.—*Comparison of average catch composition and rate of cropping of two principal types of sport fish from 4 storage and 4 mainstream reservoirs*[1]

Item	Type of reservoir	
	Storage[2]	Mainstream
Black basses		
Percentage of angling catch	47	13
Rate of cropping	30	15
White and black crappie		
Percentage of angling catch	27	24
Rate of cropping	20	11

[1]Data from: Fetterolf (1955); Eschmeyer and Tarzwell (1941); Tarzwell (1941); Carter (1957); F-2-R Job Completion Report, Tennessee Game and Fish Commission, unpublished.
[2]Includes storage, flood control, and power reservoirs.

Although angling and commercial fishing take 13 pounds of food fish per acre annually, TVA biologists have concluded that catches of food fish could probably be increased 5-fold without seriously reducing the catch per unit of commercial fishing gear (Tarzwell, 1945).

This information on the fish populations and fisheries not only shows differences between the two types of reservoirs, but clearly demonstrates that the fishery resources are greatly underexploited. On the average, angling takes only 2 percent of the weight of fish from storage reservoirs annually. The fact that sport-fishing regulations on these waters have been liberalized emphasizes the inefficiency of sport fishing as a method of cropping. Food and panfish species offer the best opportunity for expanded utilization.

Special Problems of Tailwaters and Tributaries

The drawing of waters from the cold depths of the reservoirs and discharging them directly into rivers or reservoirs below probably represents the biggest threat to the fishery potential of the Southeast. "Reservoir" management must then include special consideration of downstream (tailwater) areas. Usually waters discharged below mainstream and flood-control reservoirs are warm. Below storage reservoirs, and to a lesser extent on power reservoirs, most water discharges are cold (less than 70° F.)

All storage and power reservoirs in the Southeast are located on warm-water streams and the discharge of cold water below the dams accordingly has had profound effects on the fish populations. Where reservoirs such as Bull Shoals Dam in Arkansas and Lake Cumberland in Kentucky, are on large streams, warm-water fisheries may be eliminated for distances up to 200 miles.

Excellent put-and-take trout fisheries have been established below many storage reservoirs. Seldom do these fisheries extend beyond 15 miles below the dam even though conditions may appear to be suitable for trout farther downstream. In Tennessee, trout fisheries have been established below 10 storage reservoirs (Pfitzer, 1953). Although these trout fisheries are valuable in many ways, they solve only a small part of the problem created by cold-water discharges. Many miles of streams and upper embayments of some reservoirs support adequately neither a warm- nor cold-water fishery.

When dams are constructed in a series along a stream, discharges of cold water from upstream reservoirs may damage seriously warm-water fish populations in downstream impoundments.

In two localities, below Center Hill Dam in Tennessee and Lake Cumberland Dam in Kentucky, discharges from the depths of the reservoir are not productive of aquatic organisms in any numbers for 20 miles below the dam. Reasons for this situation have not yet been determined. Waters discharged below Roanoak Rapids Reservoir in North Carolina have sometimes been found to lack adequate oxygen to support fish life.

Another problem is the excessively high discharge from some storage and power reservoirs that makes effective fishing nearly impossible. At other localities, water discharges may be entirely shut off long enough for the cold waters downstream to become warm.

Fish populations of streams tributary to reservoirs likewise have been affected adversely by impoundment. For example, one formerly excellent 35-mile sport-fishing stream in Tennessee was found to contain a fish population, consisting of 75 percent large non-sport fish by weight, that had migrated from a downstream reservoir.[5] These fish were principally carp, smallmouth buffalo, freshwater drum, and gizzard shad. Except for the extreme lower regions of the stream, there was little evidence that sport fish migrated upstream from the reservoir. Investigations in many other Tennessee streams revealed similar influxes of non-sport fish from reservoirs (Ruhr, 1957).

Fishermen and biologists in the Southeast are increasingly concerned about the impoundment of high-value smallmouth bass streams. The total mileage of streams producing good warm-water sport fishing is being reduced rapidly. Although economic considerations may force the impoundment of many more of these streams, some natural streams with high fishery values should be preserved.

Development and Application of Sound Management Procedures

A sound, well-rounded program for the betterment of reservoir fisheries must be developed along several lines. Every known practicable method for the improvement of fish stocks and their utilization should be tested and a constant search prosecuted for new techniques. Fish populations should be managed to give greater productivity, improve species composition, and increase availability. In many reservoirs commercial fishing may prove an effective and profitable tool for population control. Sport fishermen should be educated into more effective methods of fishing and into the acceptance of a wider range of species. The intensity of angling should be increased through the provision of more and better facilities.

If this program is to prove effective it must have the support of continued research—research to test procedures, research to find new procedures, research to learn better the biological processes whereby fish are produced.

If management is to be placed on a sound basis it should be borne in mind that the chemical and physical characteristics which determine reservoir productivity are largely the interaction of: the configuration of the basin; the age of the reservoir; the quality and quantity of inflowing water; and the type of water discharge. Sound management on individual reservoirs

[5] Parsons, John W. 1953. A preliminary report on the fish population studies of Obed and Emory Rivers, Tennessee, 12 pp. [Mimeographed]

calls for familiarity with their specific problems and knowledge of the results of management and research on other similar waters.

The question of inefficient utilization of reservoir fishery resources has but one answer—that of increasing fish yield. Attempts to achieve increased yield should not, however, seriously reduce the pleasures of sport fishing. The recognized approaches to increasing fish yield from a reservoir are many. Those considered most important are: increasing the numbers or availability of catchable fish; managing the fishing and fishermen; and protecting or reclaiming fisheries in waters affected by reservoirs.

Control of Species Composition and Availability of Fish

WATER-LEVEL CONTROL

Water-level fluctuation in the multi-purpose reservoirs of the Southeast is controlled for three principal purposes: power, navigation, and flood control. Fish populations and angling success may be damaged or improved as a result of these regulated water-level fluctuations, depending upon particular conditions and the type of reservoir. Water-level control for fishery management may be compatible with or opposed to water levels regulated for purposes of the reservoir project. Since fishery management likely would require modification of standard patterns of water-level fluctuation, recommendations must be balanced with other water uses (Parsons and Crossman, 1955).

For maximum flood control and power benefits, in most reservoirs, near-maximum levels are reached in late winter and spring and minimum water levels in late fall and early winter. Water levels may fluctuate annually as little as 4 feet or as much as 150 feet, depending upon the reservoir usage. Water-level regulation for mosquito control, practiced mostly on TVA waters, consists of periodic lowering and raising the levels about 1 foot during the summer.

Fishermen and boat-dock operators on many southeastern reservoirs contend that fishing success falls off during rapid lowering of the reservoir. Most reservoirs have the greatest fishing pressure and fish catch during April, May, and June.[6] This season contributes nearly one-half of the total annual yield of sport fish. Severe drawdowns during that time could, then, materially reduce the total annual catch. On the other hand, stabilization of water levels over the same period may improve fishing.

In some reservoirs, rapid spring drawdowns expose black bass nests or subject them to shallow-water conditions. In either event, the adult bass desert the exposed nests. Without question many bass eggs are lost during severe drawdowns; usually, however, more than ample young bass are

[6] Eschmeyer and Tarzwell, 1939; F-2-R Job Completion Report, Tennessee Game and Fish Commission (unpublished).

produced despite the loss of some eggs. Where bass are scarce or lack of spawning areas limits reproduction, water-level stabilization in the spring for increasing the number of young bass hatched may be necessary.

Young largemouth bass of southeastern reservoirs feed principally on young gizzard and threadfin shad and/or sunfishes. When shad spawn late or bass spawn earlier than usual, the young bass are able to eat the young shad throughout a portion of the year. When bass spawn late, the shad may immediately outgrow the young bass and therefore not be available. Under such conditions, the young bass must depend on young sunfishes as their main food. Rapid drawdowns in late spring and early summer, may so reduce the production of small sunfishes as ultimately to reduce the survival and growth of the young bass. Where low production of young bluegills and sunfish may limit a bass or bluegill fishery, water-level stabilization during the late spring and summer should be considered. Several states, including California and Nevada, have stocked threadfin shad in reservoirs where fluctuating water levels have seriously reduced the production of small bluegills as forage, and thereby exposed young bass to excessive cannabalism (Kimsey, 1954). On the other hand, where sunfishes may be overly abundant, rapid draw-down may be exercised as a method of control.

Fluctuation of the water level offers a reliable method for the reduction of a carp population in one storage reservoir in Tennessee.[7] Carp spawn in this impoundment in May and early June usually in water less than 2 feet deep. The eggs adhere to all types of bottom materials, particularly land vegetation that had grown during the previous summer's drawdown. Here a 2-foot drawdown would destroy carp eggs. This type of carp control should not be undertaken, however, until the need for it is established. For example, studies in the reservoir just mentioned proved that the carp was not detrimental to the sport-fish population. The carp fed mostly on detritus; large numbers of bluegill followed the carp during the spawning period and fed heavily on carp eggs. Later they consumed carp fry. Furthermore, the bluegill concentration along the shore lines during that time resulted in especially good catches of this fish. Similar conditions may exist in other impoundments.

Some fishery workers in the past have assumed that the low water volumes resulting from heavy summer and fall drawdowns may have the following effects: improve the availability of sport and commercial fish; increase the availability of forage and other small fish to predators; increase availability of fertilizing elements in the soils of exposed and dried mud flats at later increases of water level; allow growth of land vegetation on the exposed reservoir basin during low water to provide fertilizer and fish cover at higher water levels; and expand the fish population as a result of the great

[7] F-2-R, Job Completion Report, Tennessee Game and Fish Commission, (unpublished).

increase in water volume in the spring. These considerations have been sufficiently discussed by Wood (1951) and Ellis (1936). In most waters the extent to which these alleged benefits actually accrue can only be conjectured. The Arkansas Game and Fish Commission, however, increased commercial catches by lowering fall water levels on flood-control reservoirs (Hulsey, 1956).

In the uses made of water-level control in fishery management, certain basic considerations apply to each of the several types of reservoirs. Water-level fluctuations for project purposes on most mainstream, power, and storage reservoirs appear to be reasonably compatible with fish production and catch. Modification of water-level fluctuations for fish on mainstream and power reservoirs may result in only limited fishery benefits. However, water-level fluctuations exceeding 2 feet per month during spring and early summer should be avoided on most storage reservoirs whenever possible.

The excessive water-level fluctuations of single-purpose flood-control reservoirs create many fishery problems. Since the flood-control function cannot be compromised greatly, recommendations for modification of water-level stages must be reasonable. The greatest opportunity for development of fisheries on flood-control reservoirs, lies in establishing a larger seasonal conservation pool to provide additional storage capacity. These pools during summer should constitute at least one-fourth of the total pool area at spillway level. Waters can then be lowered in the fall to increase the reservoir capacity for flood control prior to the winter rains. Further reduction of pool levels will provide increased opportunities for commercial fishing; however, the effects of these drawdowns upon sport fish are not well understood.

Although certain applications of water-level manipulation to management can be termed general, individual reservoirs will require close investigation before maximum benefits through this method can be realized.

TIMBER CLEARING

The effects of disposition of timber in reservoir basins on fisheries long has been a most controversial subject. Fishery workers themselves have various opinions on this subject but they generally agree that timber left standing in deeper portions of a reservoir is not harmful and that parcels of timber in the zone of water-level fluctuation along the shorelines will attract and concentrate sport fish for easier catching.

Principal controversy arises as to where and how much timber should be left along the shorelines. This issue is also of considerable economic importance in view of the costs of timber clearing.

It has been conjectured that extensive timber in a reservoir basin may result in harmful chemical combination in the nutrient materials. Indeed, variations in the amount of timber may account for variations in the quality of water discharged downstream from reservoir depths.

There is every reason to believe that the proper disposition and use of standing timber may be a means of increasing fishing success. The effects of various clearing procedures upon the catch of fish must be learned before selective clearing can be adopted as an effective fishery-management tool. Experiments of this type are expected to be made in Table Rock Reservoir in Missouri, and Hartwell Reservoir, Georgia and South Carolina.

BRUSH SHELTERS

Fishermen and dock owners in the Southeast generally favor the installation of brush shelters in large reservoirs but most state conservation agencies consider them ineffective for the improvement of fishing. At the suggestion of the U. S. Fish and Wildlife Service, brush shelters have been constructed in several reservoirs by the Corps of Engineers during timber-clearing before impoundage. The Tennessee Game and Fish Commission is now experimenting with brush shelters on two large reservoirs.

Most "brush shelters" in the Southeast are actually two or three crossed logs or trees cabled together and attached to the reservoir bottom. It has become increasingly evident that logs serve better than brush to attract catchable sport fish. If shelters prove desirable, selective timber-clearing may eliminate any need for brush-shelter programs in new impoundments.

SELECTIVE KILLING OF FISH

The value of selective killing of gizzard shad with rotenone is a matter of controversy. Many tons of shad have been killed by this method. The technique was originally designed to provide more food and space for fish such as bluegill and crappie. At present, evidence is lacking that selective killing actually increases desirable fish. In view of the great reproductive potential of gizzard shad any beneficial effects are short-lived.

Application of rotenone has been followed by a sharp increase in fishing success shortly after treatment. This improvement of fishing obviously results from the destruction of the food of predators. At present, it appears that selective killing affects the catch rather than the actual abundance of sport fish. Selective killing may, nevertheless, prove to be valuable in certain situations.

Experimental selective killing in Kentucky led biologists there to conclude that present methods may be practical only on relatively small reservoirs.

COMMERCIAL FISHING

Commercial fishing appears to be the best means by which a higher and more balanced yield of fish can be taken from reservoirs. A continual con-

fflict has existed for many years between sport and commercial fishing interests on southeastern reservoirs. Invariably, sport fishermen succeed in efforts to bar or restrict commercial fishing. Because of this controversy and problems of marketing food fishes, no strong demand has been made for commercial fishing rights in several reservoirs where high-value commercial species are abundant. Carp and suckers can be taken from many waters by gig, bow and arrow, or snagging; however, these methods, although desirable for increased pleasure, do not ordinarily contribute substantially to the total take of fish.

Commercial fisheries, properly regulated, can greatly increase the take of fish from some reservoirs, and the selectivity of the gear for non-sport fish should tend to offset effects of the selectivity of angling for more valuable species.

For effective commercial fishing, there should be an understanding of the economics of the fishery and of the biological features of the fish population. Investigations should determine the capability of a particular reservoir to support a commercial fishery and the best means by which these fish can be removed without unnecessary conflict with sport fishing (Dryer, 1955). Since sport fish constitute only 1.2 percent of the commercial gear catches from Alabama waters of the TVA reservoirs (White, 1956) there is little probability that expanded commercial fishing will result in excessive mortality of sport fish.

INTRODUCTION OF NEW FISH SPECIES

Some reservoirs contain vast numbers of forage fish, principally gizzard shad. This fish has a high reproductive potential and short life span. On some reservoirs it makes up 50 percent of the weight of all fish. Biologists in the Southeast have, therefore, reasoned that the introduction of certain predator sport fish will provide additional fishing by converting shad into sport fish. Some have suggested that species of fish native to impounded streams are best suited for reservoir habitat. This view does not appear entirely sound and should not preclude consideration of the introduction of new fish species.

Most southeastern reservoirs are naturally populated with bluegill, white or black crappie, and largemouth, smallmouth, or spotted bass. White bass and walleye, which usually appear naturally in mainstream reservoirs, must often be introduced into storage, power, or flood-control impoundments.

Sport fish preferred for stocking in the Southeast have been white bass, walleye, and in some waters, rainbow trout. Other species stocked experimentally have been muskellunge and striped bass.

Unless already present, white bass have been stocked in almost every large reservoir in the Southeast. Usually the introduction of 100 adult fish has been sufficient to establish the species. After stocking, white bass ordinarily

became common in the reservoir and contribute materially to the sport fishery. White bass provide sport fishing at all times of the year. The fish tend, moreover, to inhabit the headwater areas of major embayments where the success of sport fishing often has been limited.

Walleye frequently have been introduced as adults or fry. Usually these fish contribute substantially to the fishery only in those reservoirs where they occur naturally. Fry are stocked annually to sustain a valuable walleye fishery in Center Hill Reservoir, Tennessee (Fetterolf, 1957), an impoundment in which this fish has not reproduced naturally. Anglers have taken walleye larger than 20 pounds. The stocking of walleye in southeastern reservoirs appears never to have had undesirable results.

Rainbow trout have been planted with varying degrees of success in cold-water reservoirs. These reservoirs usually are small and are cold because inflowing waters are discharged from the depths of storage reservoirs upstream. Introductions of other cold-water fishes have met with little success.

The stocking of seven small muskellunge in Dale Hollow Reservoir in Tennessee indicates the possible value of this fish. Three of the stocked fish are known to have been taken by angling. One tagged fish weighing 2½ pounds at the time of planting weighed 7¼ pounds when it was taken 11 months later.

The striped bass presently supports a sizable fishery in the Santee-Cooper Reservoir in South Carolina (Scruggs and Fuller, 1955). Some of these fish are now taken in the newly impounded Jim Woodruff Reservoir in Georgia, Alabama, and Florida. Both adults and fry have been stocked in several reservoirs in South Carolina, North Carolina, and Arkansas but there is no evidence of success.

In view of the many desirable features of the threadfin shad, it has been placed in several southeastern storage and power reservoirs to correct a lack of small forage fish. Its short life span and small size make it ideal as forage to all sizes of predator fish (Parsons and Kimsey, 1954). The effect of this fish on sport fishing or in suppressing gizzard shad populations has not been reported. However, introduction of the species in waters where gizzard shad do not occur has been followed by promising increases in fishing success. One such reservoir in Virginia is now being studied to determine the influence of threadfin shad upon the fishery.

Threadfin shad have provided vast quantities of food in tailwaters where they were discharged in a dead or dying condition through the turbines.

The judicious stocking of desirable fish in reservoirs of the Southeast thus appears to be useful in fishery management. Introductions of new species and stocking of established ones should be done with caution, however, especially where fish populations may be relatively unstable, or the value of the fish to be introduced has been untested.

Management of Tailwaters and Tributaries

Management in tailwaters is concerned principally with control of rate of flow, with the better utilization of areas not suitable for trout but too cold for native warm-water fish, and with the improvement of water quality.

Aside from refinements in the determination of stocking needs, trout fisheries in tailwaters can be improved by providing periodic flows below the dams (Parsons, 1957). Water usage for power from storage reservoirs in the Southeast is often limited during the summer. At times no water may be discharged for several days. In tailwaters containing trout, these shutdowns can seriously affect or eliminate the populations. Analyses of the physical characteristics and water usage of the reservoirs can usually provide recommendations for periodic water discharges to avoid such occurrences. Moreover, flushing of the stream washes many terrestrial fish-food items into the tailwater. Periodic water discharges below a dam must be predetermined in order that necessary additional water may be retained in the reservoir for that purpose. Below several dams in the Southeast, the periodic release for trout is one turbine-unit discharge for 1 hour within any 48-hour period (Parsons, 1957). To increase the catch of trout, low-water flows should be provided weekends and holidays when fishing is heavy.

Certain segments of cold tailwater streams not suitable for trout (which may be determined easily by trial-and-error stocking of 4- to 6-inch fish) do not presently support any fishery. Smallmouth bass and other warm-water fish do not reproduce successfully and fish growth is slow in these waters. Most evidence indicates that a majority of the warm-water fish migrate downstream or into warm-water tributaries soon after reservoir operation begins.

Bottom samples in these stream segments indicate that food is abundant enough to support sizable fish populations. Exact determination of the types of food available will be necessary to decide which types of fish are most suited for the waters. Since the warm-water species of sport fish indigenous to the streams of the eastern United States avoid these cold areas, experimental stocking of exotic species may be desirable.

The limited abundance of fish and aquatic organisms in waters below some storage dams indicates the need for improving water quality. Total fishery values of reservoirs and downstream waters would be greatly increased if water for generating power could be drawn from any depth or in many cases, through conduits near the reservoir surface.

No investigations have been conducted to determine the effects of migrant fish (from reservoirs) on non-migratory fish in tributary streams but large-scale invasions surely must be harmful. Small dams on some of these streams have materially reduced upstream migrations (Ruhr, 1957). Installation of others may prove desirable. In Tennessee, the catch of these migrant fish from some streams has been increased by legalizing gigging and bow-and-arrow fishing.

Promotion of Angling and Regulation of the Fishery

Fishing Facilities

Utilization of reservoir and tailwater fishery resources can be increased without long periods of investigation. Public access for boat launching and public lands for shore fishing and picnicking are presently adequate on most reservoirs in the Southeast. On some reservoirs, however, the public must pay for access to public waters.

On reservoirs constructed by TVA and the U. S. Army Corps of Engineers, boat dock and harbor rights are leased to concessionaires. These private agencies may handle boats, motors, and fishing tackle and operate restaurants, cabins, and boat-launching facilities. Alert concessionaires have increased fishing by such additional facilities as: fishing docks, apart from the operator's docks, which are used for a small fee primarily by older fishermen and children; fishing cruisers for party-boat fishing, particularly at night; and heated house docks for winter fishing. These concessionaires have found that provision of fishing facilities for the entire family increases the number of fishermen and the frequency of visits.

Although development of private enterprises is not a biological problem, support by biologists for facilities at boat docks can improve utilization of fisheries.

Control of Pleasure-Boating

Only a few years ago fishing was by far the major recreation on southeastern reservoirs. Since 1950, the increase in numbers of pleasure craft has been tremendous. Few fishermen blame pleasure boating for poor fish catches. Rather, fishermen are opposed to interference by noisy, speeding boats and the frequent dangers of collision or capsizing.

This problem on reservoirs has been discussed by many groups but as yet no action has been taken. One solution may be to zone certain areas for pleasure-craft use. For the protection of fishermen on state-owned reservoirs some states have restricted the size of motors, or have banned pleasure-boating on specific week days. As this problem becomes more acute, fishermen will require state or federal protection in their desire for safe fishing.

Elimination of Restricted Areas

Warm-water tailwaters below mainstream dams offer some of the best "reservoir" fishing. It has been estimated that 40 to 50 percent of the fish catch on TVA waters is immediately below the dams (Tarzwell, 1941). "Fish sanctuaries" have been established below several dams in the Southeast. Most or all of these restrictions should be removed in the states where they exist. Other tailwater areas may be closed to fishing in the interest of public safety. However, statistics on drownings show that tailwater fishing is rea-

sonably safe. Unless conditions are unusually dangerous, shore and boat fishing should be allowed in tailwaters except immediately below the penstocks or from dam structures.

LAWS AND REGULATIONS

Most of the southeastern States have liberalized sport fishing on reservoirs. There are no closed seasons on warm-water sport fishes. In some states regulations on reservoir sport fishing could scarcely be improved. Probably the greatest increase in the catch of sport fishermen in mainstream reservoirs would be had by legalizing snagging of all fish in tailwaters immediately below the dams.

Regulations most limiting to reservoir fisheries apply to commercial or food fish. Gigs, bow and arrow, harpoons, snagging, hand fishing, and certain efficient commercial fishing devices are outlawed in many states.

Research and Interagency Cooperation

RESEARCH

Recognition of fishery problems and possibilities of management in the Southeast has been generally adequate. Lacking, but indispensable, are knowledge of facts and understanding of basic principles necessary to implement management properly. More intensive continuing research by competently trained biologists is necessary to achieve this goal.

One of the greatest needs is evalution of fishery-management practices that are put into effect. Seldom have biologists had the opportunity to study a reservoir over a period of time, initiate management, and evaluate the results. Biologists have necessarily conducted inventories of fishing and fish populations and, until this preliminary work is completed, basic research will be neglected. Furthermore, only a few universities in the Southeast have fishery curricula that can assist state research programs.

Intensive long-term research on at least one of each of the 4 types of reservoirs in the Southeast is needed badly. Better understanding of factors that affect fishing is necessary on one reservoir before findings may be applied to other waters. Among the limnological and fishery problems in reservoirs that need attention are water quality, production of bottom organisms and plankton, population dynamics of fish, predator-food relationships, and effects of water levels on the reproduction and growth of fish.

The difficulty of investigating fish populations of reservoirs has long been recognized. Studies of the many large reservoirs are complicated by artificial, as well as natural, influences. Steep shorelines and deep waters make fish sampling difficult. In addition, too few efforts have been directed toward improving or devising methods and techniques for reservoir study. For example, rotenone long has been used to sample fish but the actual value of the population data collected has never been adequately determined and improved methods for using the toxicant have not been developed.

Extensive experimentation in the use of rotenone should reveal its value

and limitations for sampling reservoir fish. Monthly samples taken from the same coves and different coves, both day and night, over a period of at least 1 year, should reveal information that will clarify some sampling problems. A good schedule would require about six 1-acre samples per month. Experiments in sampling deep waters also should be undertaken.

BIOLOGISTS AND TRAINING

Some biologists and administrators in the Southeast believe that an effective fishery-management program on any one large reservoir will require the full-time services of at least one fishery biologist. Notwithstanding the several-fold increase in biologists and students investigating reservoirs since 1949, demands are presently far beyond the researcher's capacities. The shortage of biologists is acute.

Many state biologists with experience on reservoirs are leaving the Southeast as a result of low salaries. So few southeastern universities are training fishery biologists that administrators must recruit elsewhere in an attempt to fill positions. The lack of facilities for graduate training in fisheries in the Southeast is readily understandable. The few universities that indicate an interest in fresh-water fishery courses suffer a shortage of funds. State, federal, and even private agencies then must emphasize to universities the need for fishery curricula. Furthermore, these agencies should aid in their establishment and maintenance.

None of the fishery curricula in universities of the Southeast have emphasized reservoirs in their training or research. Advances in fishery education are possible through grants to universities for training or research on reservoirs. At least, scholarships for graduate students can be granted for the study of special reservoir problems.

The lack of fishery training is only a part of the personnel problem. More incentive must be given to young people of college age to enter the fishery field. Especially needed are better salaries, more reasonable security, and earlier recognition of ability (King, 1956).

COORDINATION OF PROGRAMS

Fishery management on reservoirs may require the efforts of several agencies. Since large reservoirs are constructed solely for other purposes, fishing and recreational developments ordinarily cannot compromise major project uses. At present, fishery management must emphasize measures that can be incorporated into the construction or operation of the project.

Fishery investigations of the Southeast frequently require cooperation of conservation, construction, and water- or power-use agencies (Parsons and Crossman, 1956). Cooperation of these agencies in the past has been excellent. Construction and water-use agencies nevertheless have wisely demanded facts to justify recommended changes in reservoir construction or operations for fisheries.

Appraisal of the Present Status of Fishery Management On Reservoirs

The principal fishery problems on reservoirs are: inadequate cropping of fish populations, selective fishing, and deleterious efforts of reservoirs upon downstream and tributary waters.

Principal procedures for fishery management are based on: control of water level and flow, selective timber clearing, introduction of new fish species and other controls of species composition, improving fishing facilities, and education of the public.

Problems of research and management of reservoirs appear to be complex but in many ways they are relatively simple. They appear difficult only because of the lack of research upon which effective management must be based. To give just one example, we are in poor position to make use of the opportunities that exist for controlling water levels for fishery management on most reservoirs because we have not had the research necessary to determine when and how water levels should be manipulated.

Research will not give immediate and unequivocal solutions to all reservoir problems. Many, perhaps most, may be solved only by trial-and-error management, but, properly conducted, this type of program is in itself good research. Education of the public, as slow as it may be, is vitally important if results of investigations are to be applied and reservoir fisheries properly exploited. Fishing regulations as well as tradition still make the fishermen selective for certain fish. Furthermore, large numbers of reservoirs in existence or soon to be constructed and the relatively sparce human populations in the Southeast long will make it difficult to persuade anglers to seek small or less desirable fish. The unfortunate expression "rough fish" has not inspired fishermen to take species so categorized.

In view of the attitude of the fishermen, fishery management of reservoirs must favor the development of high-value sport fishing. Acceptance of this view requires that we meet the strong demands of the fishermen for fishing of the highest quality. At the same time we must continue to increase the use of food and pan fish by sport fishermen and by commercial operations. Ultimately, reservoir fishery management should become merely a process of balancing optimum fish removal with fish production.

Acknowledgments

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Literature Cited

Carter, Ellis R.
1954. An evaluation of nine types of commercial fishing gear in Kentucky Lake. Trans. Ky. Acad. Sci., Vol. 15, No. 3, pp. 56-80.
1955. The harvest and management of game fishes in Kentucky Lake and its tailwaters. Fish. Bull. No. 15, Ky. Dept. Fish and Wildlife Res., 14 pp. (mimeographed).
1957. Investigations and management of the Dewey Lake fishery. Proc. 10th Ann. Conf. Southeastern Assoc. Game and Fish Comm. (1956), pp. 254-270.
Chance, Charles J.
1955. Unusually high returns from fish-tagging experiments on two TVA reservoirs. Jour. Wildlife Man., Vol. 19, pp. 500-501.
Chance, Charles J. and Lawrence F. Miller
1952. Fish sampling with rotenone in TVA reservoirs. Jour. Tenn. Acad. Sci., Vol. 27, pp. 214-222.
Dryer, William R.
1955. Commercial fisheries management. Proc. 8th Ann. Conf. Southeastern Assoc. Game and Fish. Comm. (1954), pp. 34-36.
Ellis, M. M.
1937. Some fishery problems in impounded waters. Trans. Am. Fish. Soc., Vol. 66 (1936), pp. 63-75.
Elser, Harold J. and R. D. Van Deusen
1954. Deep Creek Lake Report. State Md. Nat. Resources, Resources Rep. No. 3, 19 pp.
Eschmeyer, R. W.
1946. Have we overregulated our sport fishery? Int. Assoc. Game and Fish and Cons. Comm., Vol. 20, pp. 3-11.
Eschmeyer, R. W., D. E. Manges, and O. F. Haslbauer
1946. Spring fishing on several TVA storage reservoirs, 1945. Jour. Tenn. Acad. Sci., Vol. 21, pp. 78-88.
Eschmeyer, R. W., Richard H. Stroud, and Alden M. Jones
1944. Studies of the fish population on the shoal area of a TVA main-stream reservoir. Jour. Tenn. Acad. Sci., Vol. 19, pp. 70-122.
Eschmeyer, William R. and Clarence M. Tarzwell
1941. An analysis of fishing in the TVA impoundments during 1939. Jour. Wildlife Man., Vol. 5, pp. 15-41.
Fetterolf, Carlos M., Jr.
1955. Catch statistics and fisherman counts on Dale Hollow and Center Hill Reservoirs, January, 1951-June, 1954. Proc. 8th Ann. Conf. Southeastern Assoc. Game and Fish Comm. (1954), pp. 36-43.
1957. Stocking as a management tool in Tennessee waters. Proc. 10th Ann. Conf. Southeastern Assoc. Game and Fish Comm. (1956), pp. 275-279.
Hulsey, Andrew H.
1957. Effects of a fall and winter drawdown in a flood control lake. Proc. 10th Ann. Conf. Southeastern Assoc. Game and Fish Comm. (1956), pp. 285-289.
Kimsey, J. B.
1954. The introduction of the redeye black bass and the threadfin shad into California. Calif. Fish and Game, Vol. 40, pp. 203-204.
King, Willis
1956. Highlights of progress in fish management in the Southeast, 1946-1955. Proc. 9th Ann. Conf. Southeastern Assoc. Game and Fish Comm. (1955), pp. 35-40.
Manges, Daniel E.
1950. Fish tagging studies in TVA storage reservoirs 1947-1949. Jour. Tenn. Acad. Sci., Vol. 25, pp. 126-140.

Miller, Lawrence F.
1951. Fish harvesting on two TVA mainstream reservoirs. Trans. Am. Fish. Soc., Vol. 80 (1950), pp. 2-10.
Miller, Lawrence F. and Paul Bryan
1948. Fish migrations in backwater areas on Wheeler Reservoir. Jour. Tenn. Acad. Sci., Vol. 23, pp. 236-242.
Parsons, John W.
1957. The trout fishery of the tailwater below Dale Hollow Reservoir. Trans. Am. Fish. Soc., Vol. 85 (1955), pp. 75-92.
Parsons, John W. and C. C. Crossman
1956. An example of State and Federal cooperation in establishing water control for fisheries management purposes. Proc. 9th Ann. Conf. Southeastern Assoc. Game and Fish Comm. (1955), pp. 108-110.
Parsons, John W. and J. Bruce Kimsey
1954. A report on the Mississippi threadfin shad. Prog. Fish-Cult., Vol. 16, pp. 179-182.
Pfitzer, Donald W.
1954. Investigations of waters below storage reservoirs in Tennessee. Trans. 19th N. Am. Wildlife Conf., pp 271-282.
Ruhr, C. E.
1957. Effect of stream impoundment on the fish populations of tributary streams. Trans. Am. Fish. Soc., Vol. 86 (1956), pp. 144-157.
Scruggs, George D., and Jefferson C. Fuller, Jr.
1955. Indications of a freshwater population of striped bass *Roccus saxatilis* (Walbaum), in Santee-Cooper reservoirs. Proc. 8th Ann. Conf. Southeastern Assoc. Game and Fish Comm. (1954), pp. 64-69.
Swingle, H. S.
1954. Fish populations on Alabama rivers and impoundments. Trans. Am. Fish. Soc., Vol. 83 (1953), pp. 47-57.
Tarzwell, Clarence M.
1941. A second season of creel census on four Tennessee Valley Authority reservoirs. Trans. Sixth N. Am. Wildlife Conf., pp. 202-221.
1945. The possibilities of a commercial fishery in TVA impoundments and its value in solving the sport and rough fish problems. Trans. Am. Fish. Soc., Vol. 73 (1943), pp. 137-157.
Thomas, Nathan O. and G. Earl Harbuck, Jr.
1956. Reservoirs in the United States. Geo. Surv. Water-supply Paper 1360-A, 99 pp.
Wiebe, A. H.
1940. The effect of density currents on the vertical distribution of temperature and dissolved oxygen in Norris Reservoir. Jour. Tenn. Acad. Sci., Vol. 15, pp. 301-308.
White, C. E., Jr.
1956. Fish catches with various types of commercial gear used in TVA lakes from June, 1954 through January, 1955. Proc. 9th Ann. Conf. Southeastern Assoc. Game and Fish Comm. (1955), pp. 80-86.
Wood, Roy
1951. The significance of managed water levels in developing the fisheries of large impoundments. Jour. Tenn. Acad. Sci., Vol. 26, pp. 214-235.

J. A. Posgay

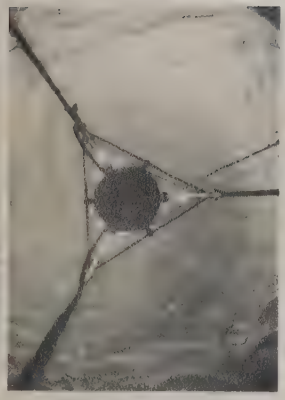
Photography of the Sea Floor

Wide angle studies of sea scallops may bring us more.

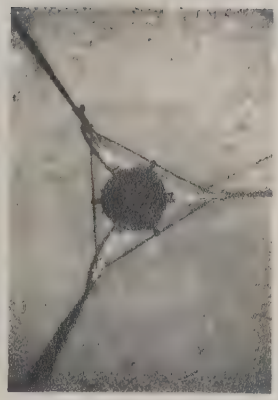
THE underwater camera has been used for studying the distribution and density of those animals which live on the sea bottom along the continental shelf. This community, in addition to being so interesting and important in the biological economy of the sea, has some members which are of direct commercial importance. The outstanding example is the sea scallop. Some twenty million pounds of sea scallop meats, worth about ten million dollars, were landed in 1957.

The traditional equipment for studying these animals has been the towed dredge and the grab sampler in a large variety of types and modifications. None of them are satisfactory. The dredge can be used only for the roughest of quantitative estimates while the grab gives reasonably valid quantitative data but each sample is small and each lowering takes up a large amount of expensive ship time. The costs of adequately surveying an area such as Georges Bank off the New England coast with a grab would be prohibitive. The proper type of underwater camera, while it has some drawbacks, enables reasonably rapid, definitely quantitative, extensive surveys to be made. A good set of underwater photographs is the next best thing to direct observation.

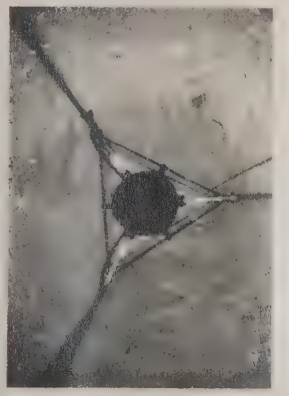
Wide-angle underwater camera being put over the side. The lower case holds the batteries, the center case the light, and the upper case, the camera. The pressure cases will withstand 1000 fathoms of pressure.



Georges Bank. 41° 37' N, 66 20' W. 48 fathoms. Fine, rippled sand with some broken shell. One badly eroded black quahog valve.



Taken one minute later about 100 feet from the previous picture, same depth. Coarse, gravelly bottom full of broken shell. Four small sea scallops.



Taken one minute later than previous picture. Same depth, same bottom. One large sea anemone, seven sea scallops ranging in size from about two inches to about six inches in diameter. This the most dense aggregation of sea scallops ever photographed. Most of the pictures taken on the ground show no scallops, more than one is unusual, seven is almost incredible.

The first practical underwater cameras were designed and built at the Woods Hole Oceanographic Institution about 1940 by Dr. Maurice Ewing and his group. Since then, many people have refined and modified the original design to suit their individual purposes and notions. The camera shown in the illustration is an improved version of a prototype designed and built at the Woods Hole Oceanographic Institution in 1955. It has several features which make it particularly suitable for investigating the animals of the sea floor.

Mr. Posgay started his underwater studies at the Institution. He now is on the staff of the U.S. Fish and Wildlife Service at Woods Hole

The heart of every camera is its lens. An ordinary commercial camera lens enclosed in a watertight case and looking out through a plate glass window has acceptable resolution over an angle of view of only twenty degrees. In order to photograph an appreciable area sharply, it is necessary to back the camera off a considerable distance. However, the water close to the continental shelf is frequently turbid, therefore, one cannot back the camera off too far, or it will not see the bottom. This camera, therefore, was built around an objective designed by Dr. E. M. Thorndike of the Lamont Geological Laboratory to operate in water at a seventy-five degree angle of view. At a height of only five feet above the bottom this camera can photograph over forty square feet. This makes it about eight times more efficient in this respect than the pioneer models.

Several other elements of the camera's design add to its utility. The exposure is made when a weight dangling below the camera touches the bottom. This allows the operator to control the location of each picture and insures that each is in exact focus. A large film magazine, automatic film transport, and recharging capacitor-discharge flash lighting permit one hundred pictures to be taken at one minute intervals without bringing the camera to the surface. The vertical axis of view and the central position of the light close to the bottom in a suitable reflector gives a fairly even degree of cross-lighting and allows for routine processing of prints. Self-contained battery power and a compact package with all delicate parts enclosed inside a very sturdy frame makes it reasonably simple and safe to use at sea.

The camera is presently being used to survey the sea scallop beds of Georges Bank. A buoy is set out, the camera is put over the side and the ship is allowed to drift. Pictures are taken at one minute intervals until the ship has drifted for a mile. The camera is taken in and the dredge set and towed back to the buoy. The camera is put over again and, since the tidal currents rotate in direction, the ship drifts off in a slightly different direction. While the next transect is being made, the animals caught by the dredge are being identified, counted, and measured. During a period of twelve hours we may obtain some 500 pictures taken along eight or ten transects radiating from the reference buoy like the spokes of a wheel. An occasional grab sample is usually taken to catch burrowing fauna. The buoy is then picked up and reset in a different location.

Back ashore, the films are developed and printed. To simplify this step, we are considering having the negatives contact printed on film strips which could then be projected. Each picture is examined for the kinds, numbers and sizes of animals visible. When these data are compared with the dredge hauls, it gives some idea of the efficiency of the dredge. The type of bottom, which among other things gives indirect evidence of the magnitude of the bottom current, is noted. Surveys repeated at the same location some time later give data from which estimates of recruitment and mortality rates can be made.

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An Observation on the Spawning of the Sea Scallop, *Placopecten magellanicus* (Gmelin), on Georges Bank

The spawning of the sea scallop, *Placopecten magellanicus* (Gmelin), was observed in late September in the natural habitat of the scallop on Georges Bank at 41° 15′ N. Lat. and 66° 22′ W. Long. The northeastern part of Georges Bank is the most productive and most intensely fished sea scallop ground on the Atlantic coast. Between 1944 and 1956, 77 million pounds of sea scallop meats (adductor muscles only) representing about 2.5 billion individuals were taken from these beds.

From September 21 to 25, 1956, an average of 250 individuals was examined each day. None of those examined on September 21 had begun to spawn, but spawning began during that night. The smaller scallops, ranging in size from 50 to 90 mm, began spawning first and were nearly spent when most of the scallops larger than 90 mm began spawning. Eighteen hours later, on September 22, 48 per cent were either spawning or already spent. At the close of the observation period on September 25, 92 per cent were either spawning or already spent.

All the sea scallops examined later at other locations on the bank were spent. Bottom temperatures were between 8° and 11°C. The trigger mechanism of the spawning is not known.

In many instances, eggs being released by a spawning female had adhered along the margin of its upper, rounded valve. Although these adherent eggs were not positively identified, they were assumed to be scallop. In all these instances, the eggs on the valve and within the gonad were the same size and color.

The condition of the gonad in the sea scallop during spawning proceeds through three distinctly different stages which can be observed macroscopically. A ripe male gonad is firm and plump with a milky-white color. When spawning begins, this coloration becomes invaded with irregular, grayish, clear channels. These clear channels gradually engulf the entire gonad. When completely spent, the gonad is collapsed and is clear or translucent. A ripe female gonad is a brilliant coral red. As spawning begins, the color fades to a pale pink and the eggs seem to be somewhat larger. Clear channels appear and invade the entire gonad as in the males. At this stage, nearly spent, the sexes become difficult to distinguish without close examination.

The time of spawning observed here closely agrees with the late September and early October period mentioned by Posgay (1950) for Cape Cod Bay. The period of spawning, however, is considerably shorter than that reported for the Digby beds by Dickie (1955).

REFERENCES

Dickie, L. M. 1955. Fluctuations in abundance of the giant scallop, *Placopecten magellanicus* (Gmelin) in the Digby area of the Bay of Fundy. J. Fish. Res. Bd. Canada, **12**: 797–857.

Posgay, J. A. 1950. Investigations of the sea scallop. Third Report on Investigations of the Shellfisheries of Massachusetts. Div. Mar. Fish., Dept. Conservation, Commonwealth of Massachusetts, pp. 24–30.

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RESULTS OF STRIPED BASS PROGRAM

(Reprinted from Appendices Section of Sixteenth Annual Report of Atlantic States Marine Fisheries Commission, April 1958)

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THE ATLANTIC STATES COOPERATIVE STRIPED BASS PROGRAM, 1952-1957

By Edward C. Raney, Coordinator (1952-1957)

A proposal for a comprehensive striped bass research program was formulated by the Striped Bass Committee of the Commission at its New York Meeting on July 16, 1952. At its eleventh Annual Meeting in Boston on September 4, 1952 the Commission unanimously approved the recommendations of the Striped Bass Committee with respect to the proposed cooperative program. On November 28, 1952 the writer was invited by Dr. Lionel A. Walford, U. S. Fish and Wildlife Service, to join his staff on a temporary appointment to act as coordinator of the program and to assist the various interested state agencies in setting up striped bass research projects. On February 19, 1953 I entered duty, began contacting state agencies, continued racial studies, and began a study of the tag returns of the Schaefer-Salt Water Sportsman tagging program.

A history of this program is contained in the several documents listed in the Striped Bass Reports incorporated in the minutes of the Commission, or of its various sections, or the Striped Bass Committee. These papers are listed in detail in the list appended to this report. Virtually all of the studies were undertaken with the assistance of Dingell-Johnson Federal Aid to Fisheries funds and progress reports of the results of these studies are on file with the several states and in the office of the U. S. Fish and Wildlife Service. Some of the results have been published and a list is appended to the report. Other studies are in press, or will be published as the various projects are brought to a close. My acknowledgments to the many biologists from Canada and this country who assisted in obtaining specimens for racial studies have been included in various published papers.

A summary by states follows:

MASSACHUSETTS.—A Dingell-Johnson project, Massachusetts Department of Natural Resources, Division of Marine Fisheries, inaugurated February 1954 with biologist J. Arthur Posgay in charge. The project continued in 1955 by biologist William A. Fitzpatrick and John Cookson. The objectives were to inventory the striped bass fishery in Massachusetts, to study winter grounds and breeding grounds of striped bass within the state, and to obtain the length, weight, age and other data on the striped bass sport fishery in Massachusetts. All have been carried out. In 1956 the project was expanded to include a study of the bluefish. In 1957 other common marine sport fishes were added to this list.

RHODE ISLAND.—Dingell-Johnson project, Rhode Island Department of Agriculture and Conservation, Division of Fish and Game in cooperation with the Narragansett Marine Laboratory of the University of Rhode Island, Kingston, Rhode Island. Biologist, Dr. Saul B. Saila in charge. Physiological studies of striped bass under way with the objective to find ways to produce and sustain under controlled conditions a sport fishery for striped bass in areas and/or at times where none existed previously.

CONNECTICUT.—Dingell-Johnson project. Connecticut Board of Fisheries and Game. Inaugurated in 1955 with biologist Craig Slater, who resigned in August 1956. Project reactivated in March 1957 by biologist George Maltezos. Objectives, by tagging and other means to determine the rate of exploitation of the striped bass by the sport fishery and to determine the source of the striped bass in Connecticut. A tagging program has been carried on and efforts are being made to measure spawning success in various rivers of the state.

NEW YORK.—A Dingell-Johnson project, Division of Fish and Game of the New York State Conservation Department, activated April 1954, with biologists Warren J. Rathgen and Louis Miller. Early emphasis was on a study of the striped bass population in the Hudson River where natural spawning was evaluated and the results published. With Rathgen's departure in July 1956, the striped bass project waned although some effort was made by marine biologists working out of Freeport, Long Island to carry on this work. The work in the Hudson River was published (see Rathgen and Miller, 1957).

NEW JERSEY.—A Dingell-Johnson project, Division of Fish and Game, Department of Conservation and Economic Development begun in 1956 with biologist Paul E. Hamer as leader. Objectives of the study were to determine the degree of competition between underwater fishermen (skin divers) and sport fishermen, to set up a Creel Census at Island Beach and to investigate the striped bass, fluke and porgy populations. A marine laboratory has been established at Island Beach. Earlier studies by the Division of Fish and Game and by Dr. James R. Westman of Rutgers University included studies of tagged striped bass and an inventory of striped bass spawning grounds in major rivers of the state.

MARYLAND.—A Dingell-Johnson project by the Department of Tidewater Fisheries in cooperation with the Department of Research and Education and the Department of Game and Inland Fish was activated in February 1954 with biologist Edgar H. Hollis in charge. Harold A. Davis, Jr. and other personnel have also worked on the project. Among the various objectives which have been obtained were studies of production of young striped bass from major spawning areas, the studies of effects of net fishing on striped bass in spawning area, the delimitation of major striped bass areas and studies of migration of striped bass. Numerous other studies of striped bass have been undertaken by Romeo Mansueti and other biologists of the Department of Research and Education at Solomons, Maryland and by zoologists of University of Maryland, College Park.

VIRGINIA.—Biologists, especially William H. Massmann, of the Virginia Fishery Laboratory have collected young, juvenile and adult striped bass for a study of the evaluation of different races within the bay. In the spring of 1957 the laboratory participated in the large-scale tagging program.

Large-Scale Striped Bass Tagging Program In Chesapeake Bay.—This program was recommended to the Commission in November 1955 by a committee consisting of Ralph P. Silliman, Chairman, L. Eugene Cronin, John L. McHugh, Edward C. Raney and Gerald B. Talbot. The objectives of the study were to determine seasonal location of striped bass populations by age classes, development of a satisfactory tag and tagging technique and an evaluation of these, locating sources of adequate tag recoveries from both sport and commercial fisheries, such that these returns will quantitatively reflect the populations available to the respective fisheries and further evaluation of the criteria that separate subraces of striped bass in Chesapeake Bay. With the assistance of Saltonstall-Kennedy funds this program was inaugurated in the spring of 1957 by personnel of the Fish and Wildlife Service, Virginia Fisheries Laboratory, Department of Research and Education, Solomons, Maryland and Dept. of Tidewater Fisheries, Annapolis, Maryland, with the assistance of biologists from Massachusetts and New Jersey. More than 3000 bass were tagged. If support is forthcoming this program will be continued.

NORTH CAROLINA.—Beginning in 1956, a major effort was expended on striped bass research. Representatives of the following agencies set up a study program: North Carolina Stream Sanitation

Committee, U. S. Public Health Service, National Council for Stream Improvement, U. S. Fish and Wildlife Service, U. S. Corps of Engineers, North Carolina Wildlife Resources Commission, North Carolina Department of Conservation and Development, University of North Carolina Institute of Fisheries Research and North Carolina State College. Task forces were set up for the following assignments: (1) Study of water quality and engineering problems; (2) Bio-assay studies on striped bass and their spawning habits and status of the fishery. These studies have not as yet been completed.

SOUTH CAROLINA.—A Dingell-Johnson project of South Carolina Wildlife Resources Department activated in March 1954 with biologist George Scruggs, Jr. in charge and with emphasis on a study of the striped bass populations in Santee-Cooper reservoirs. Several published papers have given the progress to date. Since 1956 biologist Robert E. Stevens has been in charge.

FLORIDA.—A Dingell-Johnson project, Florida Game and Freshwater Fish Commission carried on in 1954-55 by biologist William M. McLane. Major emphasis was on the study of the population in the St. Johns River in northeastern Florida.

During the period 1952-57 the Fish and Wildlife Service has furnished a part-time coordinator for the study and has provided him for assistance in carrying out racial studies. It has also published the results of some of these studies (see Lewis, 1957; Lund, 1957; and Raney, 1957). The Service has also contributed substantially to the large-scale tagging program in Chesapeake Bay and to the studies carried out in Albermarle Sound and the Roanoke River, North Carolina, none of which studies is yet completed.

The Sport Fishing Institute has cooperated by making a fellowship award available to graduate students at Cornell working on racial studies. Robert M. Lewis, William A. Lund, and Walter S. Murawski have participated in this manner.

Probably one of the more important outcomes of the striped bass program is the establishment in a number of Atlantic coastal states of units of biologists working on marine fisheries programs. These trained personnel are turning their attention to other important fisheries problems as the objectives of the striped bass program are accomplished.

The present program was limited in some states because of internal conflicts. Other projects were slowed because of lack of the type of equipment needed to pursue the studies of marine fishes. Some projects were temporarily halted by relatively poor pay scales and by lack of permanence of the positions. This resulted in frequent shifts of personnel. The coordinator had excellent cooperation from the administrative personnel and biologists of the various states and acknowledges the help and encouragement of personnel of the U. S. Fish and Wildlife Service, particularly Ralph P. Silliman, Albert H. Swartz and Gerald B. Talbot.

An Appraisal

An attempt to appraise the results of the program and their contribution toward the wise utilization of the resource should consider the local nature of most of the investigations. While many of the objectives have been accomplished on a state level, these often do not give the information necessary for management of a widespread fishery. Nevertheless the solution of some of these local problems may assist in further delimiting the larger problems.

Racial studies based on meristic, morphometric and tagging studies have shown that some populations are local in extent. Examples are the Hudson River race and the Santee-Cooper, S. C. race. The demonstration of the endemic nature of these populations necessitates a quite different management treatment, if indeed any is possible, than the problems associated with the large population of migratory striped bass which orginates in tributaries of Chesapeake Bay. Within Chesapeake Bay recent studies have supported findings of tagging experiments and have shown that several subpopulations exist. The relative importance of each of these subpopulations to the fishery within and outside the Bay is not yet known.

Recent tagging experiments in Chesapeake Bay have confirmed the result from early studies that relatively few striped bass (of the relatively small size tagged) leave Chesapeake Bay. However these fish apparently comprise the coastal migratory population which supports a fishery along the coast as far north as Massachusetts. We need to know much more about the movement of large striped bass. The high cost of purchase of these large fish for tagging and their general unavailability has deterred progress.

Local studies have delimited spawning and nursery areas. This knowledge may make it possible to save these important areas as human population and industry expand in an atomic age. The future destruction of aquatic habitat in the Chesapeake Bay area will determine to a large extent the future fishery for striped bass in coastal areas of New England, New York and New Jersey.

It is known that occasional abundant year classes such as those produced in the Chesapeake Bay area in 1934 and 1940 will greatly affect the fishery for years. The precise conditions which are responsible for the production of these dominant year classes are not known. A solution of this problem would seem to depend on long term studies on the main spawning rivers in Virginia and Maryland.

For the striped bass fishery we need to know the size of the fishery in relation to the size of the stock fished and the catch per unit effort for the several types of gear. A start has been made toward the development of better tagging techniques which may make it possible to determine the rate of exploitation of the various year classes by the several types of fishery. The lack of cooperation by some fishermen in returning tags makes it necessary to design carefully any such experiment. The quantity of striped bass caught by the sport fishery is unknown. Statistics on commercial catch are available but often not in such detail as to render them useful in determining the catch per unit effort on a sustained basis. Although the latter may someday be available there seems at present little hope for obtaining adequate sport fishery statistics. Perhaps when marine fisheries research is adequately financed through a sport fishing license or by other means such a program for collection of statistics can be set up; it was not possible under this limited program.

In future cooperative federal-state programs it is recommended that a full time coordinator be employed. There are many advantages in having this coordinator attached to an independent agency and preferably to a university. He should have some budgetary control over the various projects and a hand in choosing and directing personnel. The present coordinator acted in an advisory capacity only. In my opinion the coordination of such a program by a committee would probably result in failure.

STRIPED BASS REPORTS INCORPORATED IN THE MINUTES OF THE COMMISSION, ITS VARIOUS SECTIONS, OR THE STRIPED BASS COMMITTEE. 1952 TO 1958

1952 **Proposed Federal-State Striped Bass Research Program** by Ralph P. Silliman, Chief, Section of Anadromous Fisheries, USFWS, Appendix B, 11th Annual Meeting ASMFC, Boston, Mass., September 3-6, 1952.

1953 **Summary of Studies on Racial Analysis of Striped Bass and Results from the Schaefer-Salt Water Sportsman Tagging Program** — Dr. Edward C. Raney, Appendix 5, 12th Annual Meeting, ASMFC, New York, N. Y., October 8-9, 1953.

1954 **Quarterly Progress Report — Atlantic States Cooperative Striped Bass Program** by Dr. Edward C. Raney,

Appendix 1, Striped Bass Committee Meeting, May 12, 1954.

Status of Atlantic States Cooperative Striped Bass Program
North Atlantic and Middle Atlantic Sections
Dr. Edward C. Raney — Appendix NA-MA 6
Chesapeake Bay Section
Ralph P. Silliman — Appendix CB 2
South Atlantic Section
Ralph P. Silliman — Appendix SA 3
} 13th Annual Meeting Baltimore, Maryland October 4-6, 1954.

1955 **Striped Bass Survey, Commonwealth of Massachusetts 1954-55** Charles L. Wheeler, Appendix 1, Striped Bass Committee Meeting in Washington, D. C., April 26, 1955.

Status of Current Studies on the Striped Bass (Roccus saxatilis) in New York — Warren F. Rathjen, Appendix 2, same meeting.

Jobs and Objectives of State Striped Bass Projects in Progress with the Assistance of Federal Aid — Dr. Edward C. Raney, Appendix 3, same meeting.

Striped Bass Stocks along the Atlantic Coast — Dr. Edward C. Raney, Appendix 4, same meeting.

A Migration Study of the Cooper River Population of Striped Bass, (Roccus saxatilis) Walbaum. George D. Scruggs, an appendix to same meeting.

Summary Cooperative Striped Bass Program — Dr. Edward C. Raney, an appendix to 14th Annual Meeting, ASMFC, Virginia Beach, Va., November 14-15, 1955.

Report of Large Scale Striped Bass Tagging Experiment Committee — Ralph P. Silliman, Chairman, an appendix to 14th Annual Meeting, ASMFC, Virginia Beach, Va., November 14-15, 1955.

Massachusetts Striped Bass Project — Summary — Charles L. Wheeler, Appendix to North Atlantic Section of ASMFC, 14th Annual Meeting, Virginia Beach, Va., November 14-15, 1955.

Striped Bass Investigations in Connecticut during 1955 — Craig Slater, same as above.

Striped Bass Program — Summary — Dr. Edward C. Raney, Appendix to North Atlantic Section of ASMFC, 14th Annual Meeting, Virginia Beach, Va., November 14-15, 1955.

Progress on Striped Bass Studies Underway in New York — Warren F. Rathjen, Appendix to Middle Atlantic Section of ASMFC, 14th Annual Meeting, Virginia Beach, Va., November 14-15, 1955.

New Jersey Striped Bass Investigation — Paul E. Hamer, same as above.

Striped Bass Program — Middle Atlantic Section — Gerald B. Talbot, same as above.

Striped Bass Studies in Maryland, an appendix to Chesapeake Bay Section, ASMFC, 14th Annual Meeting, Virginia Beach, Va., Nov. 14-15, 1955.

Gonads of the Striped Bass in Chesapeake Bay — Dr. J. Frances Allen and Dr. Robert A. Littleford, same as above.

Reproduction of Resident Striped Bass in Santee-Cooper Reservoir, South Carolina, George D. Scruggs — an appendix to South Atlantic Section, ASMFC, 14th Annual Meeting, Virginia Beach, Va., November 14-15, 1955.

North Carolina Striped Bass Studies — Dr. Wiliam E. Fahy, same as above.

Striped Bass Research in Roanoke River — Gerald B. Talbot, same as above.

1956 **A Progress Report of the Atlantic States Cooperative Striped Bass Program** — Dr. Edward C. Raney, Appendix 3, 15th Annual Meeting, ASMFC, Atlantic City, New Jersey, September 21-22, 1956.

Interim Report Massachusetts Striped Bass Project — Francis W. Sargent, Appendix NA 3, 15th Annual Meeting, ASMFC, Atlantic City, New Jersey, September 21-22, 1956.

Striped Bass Studies in New York — Irwin M. Alperin, Appendix MA 7, 15th Annual Meeting, ASMFC, Atlantic City, New Jersey, September 21-22, 1956.

1957 **Current Striped Bass Laws on the Atlantic and Pacific Coasts —** Compiled by R. Mansueti and G. Murphy, Maryland Dept. of Research and Education, Ref. No. 57-44, August, 1957.

Atlantic Coast Cooperative Striped Bass Program — Dr. Edward C. Raney, Summary prepared for Biological Committee of ASMFC, September 24-25, 1957.

The Striped Bass of the Santee-Cooper Reservoir — Robert E. Stevens, distributed to South Atlantic Section, September 26, 1957. Summary as Appendix SA 2, 16th Annual Meeting, ASMFC, New York, N. Y., September 26-27, 1957.

PAPERS ON ATLANTIC COAST STRIPED BASS PUBLISHED

SINCE 1952 (For previous references see Raney, 1952)

Hollis, E H. 1952 **Variations in the feeding habits of the striped bass, Roccus saxatilis (Walbaum) in the Chesapeake Bay.** Bingham Oceanographic Coll. Bull. 14(1): 111-131.

Jackson, H. W. and R. E. Tiller 1952 **Preliminary observations on spawning potential in the striped bass (Roccus saxatilis Walbaum).** Chesapeake Biol. Lab. Publ. No. 93: 1-16.

Lewis, Robert Minturn 1957 **Comparative study of populations of the striped bass.** Spec. Sci. Rep.: Fish. 204: 1-54.

Lund, William A. 1957 **Morphometric study of the striped bass. Roccus saxatilis.** Jr. Spec. Sci. Rep.: Fish. 216: 1-24.

Mansueti, Romeo 1956 **Recaptures of tagged striped bass. Roccus saxatilis. (Walbaum), caught in deep waters of Chesapeake Bay, Maryland.** Md. Dept. Res. and Educ. Resource Study Report 10: 1-9.

Pearson, J. C. 1938 **The life history of the striped bass or rockfish, Roccus saxatilis (Walbaum).** U. S. Bur. Fish. Bull. 49(28): 825-851.

Raney, Edward C 1952 **The life history of the striped bass. Roccus saxatilis (Walbaum).** Bingham Oceanogr. Coll. Bull. 14(1): 5-97.

Raney, Edward C. 1954 **The striped bass in New York waters.** N. Y. State Conservationist 8(4): 14-16.

Raney, Edward C. 1956 **The striped bass in New Jersey. New Jersey** Outdoors 6(8): 9-13.

Raney, Edward C. 1957 **Subpopulations of the striped bass. Roccus saxatilis (Walbaum), in tributaries of Chesapeake Bay.** Spec. Sci. Rpt.: Fish. No. 208: 85-107.

Raney, E. C. and D. P. deSylva 1953 **Racial investigations of the striped bass, Roccus saxatilis (Walbaum),** Jour. Wildl. Mgt. 17(4): 495-509.

Raney, Edward C, W. S. Woolcott, and A. G. Mehring 1954 **Migratory pattern and racial structure of Atlantic Coast striped bass.** Trans. N. Amer. Wildlife Conf., 19: 376-396.

Raney, Edward C. and William S. Woolcott 1955 **Races of the striped bass, Roccus saxatilis (Walbaum), in southeastern United States.** Journ. Wildl. Mgt. 19(4): 444-450; also in Proc. Southeastern Assn. Game and Fish Comm., pp. 60-64.

Rathgen, Warren F. and Lewis C. Miller 1957 **Aspects of the early life history of the striped bass (Roccus saxatilis) in the Hudson River.** N. Y. Fish and Game Jour. 4(1): 43-60).

Scruggs, George D. 1957 **Reproduction of resident striped bass in Santee-Cooper Reservoir, South Carolina.** Trans. Amer. Fish. Soc. 1956, 85:144-154.

Scruggs, George D. and J. C. Fuller, Jr. 1955 **Indications of a freshwater population of striped bass, Roccus saxatilis (Walbaum), in Santee-Cooper Reservoirs.** Proc. Southeastern Assn. Game and Fish Comm., pp. 64-69.

Tresselt, E. F. 1952 **Spawning grounds of the striped bass or rock, Roccus saxatilis (Walbaum), in Virginia.** Bingham Oceanogr. Coll. Bull. 14(1): 98-110.

Vladykov, V. D. and D. H. Wallace 1952 **Studies of the striped bass, Roccus saxatilis (Walbaum), with special reference to the Chesapeake Bay region during 1936-38.** Bingham Oceanogr. Coll. Bull. 14(1): 132-177.

Murawski, Walter S. 1958 **Comparative study of striped bass, Roccus saxatilis (Walbaum), based on lateral line scales.** Thesis M.S. Cornell Univ.

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Shrimp Research by the U. S. Fish and Wildlife Service

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The biological studies of our shrimp laboratory encompass several types of work. Under general work, the compiling of a world-wide bibliography on the Penaiedae of over 700 titles will be submitted for publication within the next few months. Laboratory studies include determining the effect of different substrates on the rate of growth. Post-larval grooved shrimp reared on bottom covered with the stiff marsh grass, *Spartina alterniflora,* increased in length 122 per cent in 61 days, against 39 per cent when placed on bottoms covered with mud and 50 per cent on sand. These experiments are being repeated commencing with large shrimp, and already the *Spartina* covered bottom is proving superior. These experiments point out the desirability of maintaining vegetated marsh as nursery areas.

Preliminary work on reaction of shrimp to light gradients in a 12-foot tank show random movements by the white shrimp *(P. setiferus)* while the grooved shrimp *(P. aztecus)* preferred the extreme dark end of the tank.

Post-larval shrimp proved very tolerant of temperatures from 4° to 40°C. Post larvae only 12 mm long survived indefinitely at 40°C. Respiration experiments have been started to decide at what point oxygen deficiency becomes a limiting factor.

The work by Charles Dawson on the use of vital stains for marking shrimp has been published. He found red, green and blue stains that give good results. We have tested the red stain which can be fed to larval shrimp as small as 12 mm in a food mixture. After two months, 90 per cent of the marks were easily recognizable. All three stains can be used in shrimp from 30 mm and larger by injecting .01 to .02 cc. of a one per cent solution in artificial sea water isotonic to the water in which the shrimp are held. Twenty one hundred shrimp were marked and released and a few recoveries were made. Of the controls held the survival was: out of 50 green-dyed—31 in 3 months; out of 10 blue-dyed—5 in 3 months; out of 50 red-dyed—34 in 3 months. All controls, except three of those fed the red dye, were clearly marked after three months We are experimenting with another blue stain which appears to yield better survival than the one now in use.

Field studies are being carried out on shrimp while in the marshes and estuaries. One of the first problems was to discover how to obtain quantitative samples in the stiff marsh grass of the shallow waters. This was finally solved by development of a special push-type net on runners that efficiently samples young shrimp from 12 to 85 mm in length.

After preliminary reconnaissance we have selected Clear Lake as an ideal spot to determine the seasonal abundance of white and brown shrimp in an

estuarine environment. By sampling at the inlet to the lake we can obtain accurate data on the inshore and offshore movements, and the changes in size within the lake will give needed information on growth. Incidentally, we often find large shrimp in these nursery areas and this raises the question of what factors induce them to leave the inside areas. For this reason we are collecting physical and chemical data to discover any clues.

Little quantitative data are available on the effect of predation in nursery areas, but we are studying the feeding habits of the sand trout, *Cynoscion arenarius;* and other estuarine fish, since shrimp are found in most of the fish stomachs examined.

The fishery for shrimp to sell as live or dead bait has become a major industry. In a special study of the Galveston Bay area, over 200 retail bait houses sold over 82,000 quarts of live shrimp, worth over $164,000 and 50,000 pounds of dead shrimp worth over $25,000 in a four month period for a total of over $190,000. The manpower shortage precluded obtaining complete coverage, so these figures are a minimum. Damage by hurricanes to the bait fishing fleet reduced fishing pressure considerably during one of these four months. In this area the catches of the bait fishing vessels have been sampled to obtain the size and species taken.

In the Tortugas area the Service has contracted with the University of Miami Marine Laboratory to determine by sea sampling from a chartered vessel the seasonal distribution of pink shrimp by size, sex, depth and area. Service personnel will also initiate a shrimp marking project from the vessel as soon as the logistic problems of large scale marking with vital stains have been solved.

The Corps of Engineers is presently drawing up sketches and cost estimates for installing a system of running sea water at our Galveston Laboratory to include a number of outdoor salt-water tanks. These semi-controlled conditions will enable us to obtain basic information on shrimp culture that would be very difficult to work out at pilot farms.

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WESTERN NORTH ATLANTIC RECORDS OF *BERYX SPLENDENS* LOWE AND *B. DECADACTYLUS* CUVIER AND VALENCIENNES.—On the Atlantic coast of North America, there are three records of *Beryx splendens*. The first was caught by the U. S. Fish Commission R. V. Albatross in 1885 (Goode and Bean, 1895, Oceanic Ichthyology, U. S. Nat. Mus. Spec. Bull: 177) off Savannah, Georgia. Two specimens were taken in 1955 by the U. S. Fish and Wildlife Service M. V. Oregon in the Gulf of Mexico (Woods, Copeia, 1957 (4): 298–299). Recently, two more specimens of *Beryx splendens* were caught by vessels that were otter-trawling for ocean perch (*Sebastes marinus*) in the northwestern Atlantic. Both specimens are deposited in The Museum of Comparative Zoology, Cambridge Massachusetts.

The U. S. Fish and Wildlife Service R. V. Delaware caught a 216-mm. (fork length) *B. splendens* on May 14, 1955, in 320 fathoms at 42°16'N and 65°07'W., which location is a few miles outside one of the Gulf of Maine's arbitrary boundaries that have been proposed by Bigelow and Schroeder (1953, U. S. Fish. Wildl. Ser., Fish. Bull., 53: 1). About 1,000 pounds of ocean perch were caught in the same tow. This specimen has dorsal IV, 14; anal IV, 29; pectoral I, 16; pelvic II, 13; and lateral line scales, 80. The depth of the body is 34.7 percent of the fork length.

The fishing boat Flo, captained by Percy Spurling of Rockland, Maine, caught a 419-mm. (fork length) *B. decadactylus* during the week of August 19–25, 1956, in 85 fathoms in the Gulf of Maine on Jones Ground, 40 miles east of Mount Desert Rock, Maine. The fish has dorsal IV, 18; anal IV, 28; pectoral I, 16; pelvic I, 10; and lateral line scales, 70. The depth of the body is 44.4 percent of the fork length. This is the first record of *B. decadactylus* in the western North Atlantic.

These species are cosmopolitan and found in moderate depths, usually on the border of the continental shelf (Bougis, 1956, Bull. Inst. Oceanogr., 891: 1).—Leslie W. Scattergood, *U. S. Fish and Wildlife Service, Boothbay Harbor, Maine.*

Unusual Records of Gulf of Maine Fishes

By Leslie W. Scattergood
U. S. Fish and Wildlife Service

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Boothbay Harbor, Maine

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Since 1939, when biological studies began at the fishery stations at Boothbay Harbor, we have been reporting on unusual records of marine fishes in Maine waters. The information on the following fish adds to our knowledge of Gulf of Maine fishes, which has been summarized by Bigelow and Schroeder 1953 (U. S. Fish Wildl. Serv., Fish. Bull. 75:viii + 577).

Carcharodon carcharias (Linnaeus): Great white shark or "maneater." On August 15, 1957, John Snowman found a 10-foot 7-inch white shark skeleton tangled in the buoy line of one of his lobster traps off Cape Newagen, Lincoln County, Maine. The trap had been presumed lost about six weeks previously when its floating buoy disappeared. The shark probably became ensnarled in the line, and, after dying, sank to the bottom, pulling the buoy under the suface of the sea. When the flesh disintegrated and the weight of the fish decreased, the buoy once more rose to the surface, and the trap, together with the skeleton, was recovered. The fish was identified from the few teeth that remained attached to the lower jaw.

Wendell Long, Maine Department of Sea and Shore Fisheries warden, has provided us with an account of a 17-foot 6-inch white shark harpooned September 28, 1957 in Little Machias Bay, Washington County, Maine. We identified the fish from a photograph and several teeth from the lower jaw. This was the second largest white shark ever reported in the Gulf of Maine. On September 24, the shark entered Kenneth Dennison's herring weir and remained there four days. After leaving the weir, the fish swam about in the shallow bay and was shot and then harpooned by fishermen. At first, the shark was powerful enough to tow astern a 32-foot lobster boat. The fish was hauled ashore where it died. The stomach contained three harbor seals, only one of which showed teeth marks. Each seal lay in the stomach with its head forward, as if the animal had been swallowed from behind.

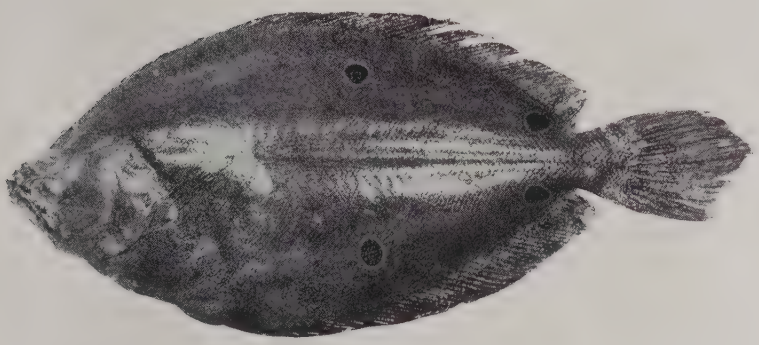

FIG. 1. A four-spotted flounder (*Paralichthys oblongus*) from Sheepscot Bay, Maine.

Paralichthys oblongus (Mitchill); Four-spotted flounder. Arthur Cochrane of Five Islands, Maine, caught a 15½-inch female, with full ovaries, while otter-trawling near Griffith's Head in Sheepscot Bay, Sagadahoc County, Maine, on June 11, 1958. This is the first record for this fish in Maine waters. A few days prior to the capture of this fish, a 14½-inch specimen was otter-trawled in Passamaquoddy Bay (Leim, *St. Croix Courier*, June 19, 1958) which represented a new record for New Brunswick, Canada, waters. The northern range of this species is off Nova Scotia where one was taken in 1880 (Ginsberg, 1952, U. S. Fish Wildlife Serv., Fish. Bull. 71:295). The four-spotted flounder appears to be plentiful along the continental shelf off Nantucket and Georges Bank, and its center of abundance apparently lies between southern New England and Delaware Bay (Bigelow and Schroeder, *ibid.*, 271). Cochrane and Robert McClellan, a Boothbay Harbor otter trawler, both of whom have been fishing locally for the past six years, report that they have seen several four-spots each year while dragging for other flounders. The fish are seldom marketed, because they are usually quite small. They call this species "fluke" and believe that other local fishermen apply the same name to this species. The summer flounder (*P. dentatus*) is known as "fluke" in southern waters, but appears to be quite rare in Maine.

Zenopsis ocellata (Storer); American John Dory. Warden Swansea Burns brought us a 6-inch specimen that had been caught in a floating fish trap at West Point, Sagadahoc County, Maine, during the autumn of 1952. The usual range of this species is over the outer part of the continental shelf. Only one other specimen has been reported from inshore Maine waters (Scattergood, *Copeia,* 1953:195).

Decapterus macarellus (Cuvier and Valenciennes); Mackerel scad. In the first week of August, 1956, Harold Wallace found an 8-inch specimen in his West Point floating fish trap. Warden Owen Richardson brought the fish to Boothbay Harbor for identification. This species is not uncommon south of Cape Cod, but in the Gulf of Maine it has seldom been reported. The West Point fish is the fourth record for Maine (Bigelow and Schroeder, *ibid.,* 375; Scattergood, *Copeia,* 1953:237).

Stenotomus versicolor (Mitchill); Northern scup. A 15-inch specimen was caught in a herring weir at Lincolnville Beach, Knox County, Maine, on June 21, 1954. A few northern scup are taken each year in pound nets at Pemaquid Point, Lincoln County, but are seldom reported from the Maine coast east of that point.

Cyclopterus lumpus Linnaeus; Lumpfish. Packard (1957, *Maine Field Nat.,* 13(3): 56) first recorded the discovery of lumpfish eggs on the Maine coast. We have information on two egg masses that have been found in Boothbay Harbor, Lincoln County, Maine. Warden Luther Greenleaf collected one mass several feet below mean low water on a wharf piling in May 1940. A lobster fisherman on May 23, 1957, found another cluster attached to his lobster trap that had been resting in six fathoms.

Bigelow and Schroeder (*ibid.,* 463) mentioned that the lumpfish is never eaten in the United States. There are several exceptions, for we know of two Gulf of Maine localities where fishermen spear and eat the male lumpfish — the New Hampshire coast and the Jonesport, Washington County, Maine region. The males are most readily captured during the spring in shallow water around rocky ledges. Females are seldom caught for food, for their flesh is not considered to be as palatable as that of the males.

Echeneis naucrates Linnaeus; Shark sucker. A 20-inch specimen was taken on August 7, 1957, from Ted Farrin's floating fish

trap at Pemaquid Point, Maine. It was brought to Boothbay Harbor and lived several weeks in the Sea and Shore Fisheries Aquarium. There is only one other Maine record (Scattergood, *Copeia,* 1952:306) of this fish which is usually found clinging to a ship or a shark.

Alutera schoepfii (Walbaum); Orange filefish. A 20-inch specimen was caught in Maurice Pye's floating fish trap at Small Point, Sagadahoc County, Maine, on August 7, 1957. Fish dealer Percy Plant kept the fish alive for several hours, but it died before we could transport it to the Aquarium. This is another species that is not unusual south of Cape Cod, but apparently seldom strays north. This is the first recent Maine record of this species; one other was reported many years ago from Portland (Bigelow and Schroeder, *ibid.,* 525).

NOURISHMENT OF CENTRAL PACIFIC STOCKS OF TUNA BY THE EQUATORIAL CIRCULATION SYSTEM

By

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NOURISHMENT OF CENTRAL PACIFIC STOCKS OF TUNA BY THE EQUATORIAL CIRCULATION SYSTEM

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An extensive program pursued by the Fish and Wildlife Service from its Honolulu laboratory for Pacific Oceanic Fishery Investigations has been directed toward discovery of high-seas fishery resources through study of oceanic productivity. This program, uniting oceanography, biology, and fishery investigation probably has amassed more information regarding the physical and chemical properties of the upper-level waters, the structure of the upper-level current system, the abundance and distribution of plankton, and the occurrence of harvestable fish in the low latitudes of the east-central Pacific than has been available previously for any mid-ocean area anywhere.

Up to March 1953 we have occupied 390 hydrographic stations forming 22 sections transverse to the equatorial current system at various longitudes from 140°W. to the 180th meridian (Fig. 1). Most of these have been accompanied by quantitative zooplankton hauls and additional plankton hauls have been made on fishing voyages, making a total of 399. There have been 218 fishing stations, forming 20 transects of the equatorial zone (Fig. 2), as well as several additional patterns of fishing survey over special areas. Hydrographic and fishing trips have provided 4,442 bathythermograms. Reports have been published, are in preparation, or are planned to cover various aspects at various stages of our progress. At this time, it is possible to give a broad preliminary outline of the results as they are now emerging.

The dominant energy source for equatorial ocean circulation is the trade wind system. In the oceanic portion of the eastern half of the equatorial Pacific, where there is practically no emergent land to impose topographical modifications, the direction and force of the wind govern rather completely the details of the equatorial current system. As a consequence of the circulation there results a chain of biological events that culminate in an abundant stock of equatorial yellowfin tuna, *Neothunnus macropterus*, Temminck and Schlegel. We shall examine first in cross-section and then in plan view this oceanic equatorial production system.

In a paper now in press Cromwell [1] has erected a hypothetical model which postulates the effect of winds from various directions on the ocean circulation and which is consistent with the empirically determined hydrographical and biological conditions. He has kindly permitted our use here of Figure 3 (Fig. 6 of his paper) and has prepared the following statement on the particular effects of wind which are most significant to the present discussion.

"Figure 3 shows directions of current transport (solid arrows) that would exist near the equator under various wind conditions were there no pressure gradient force acting.[2] For each wind direction the meridional components of current transport (dotted arrows) are drawn to emphasize the regions of divergence (Div.) and convergence (Conv.). The magnitude of the current is drawn everywhere constant, and hence the regions of divergence and convergence shown are associated with differences in current direction only. Upwelling can occur in the regions of horizontal divergence.

"The intensity of the horizontal divergence is partially dependent on the current magnitude which increases with increasing wind speed. Thus, during strong trade winds near the equator, horizontal divergence and upwelling will be intense and the sea surface temperature will be low.

"Figure 3 shows further that the position of the convergent and divergent currents depend on the wind direction. During a steady east wind horizontal divergence is centered at the equator. When the wind is southeast there is horizontal convergence in the northern part of the equatorial region between the 3° parallels, with the divergent current now centered somewhat south of the equator."

As an empirical example for examining the distribution of properties in the meridional plane, for inferring the circulation, and for seeing the effect of the circulation on plankton and tuna distribution, we shall use Cruise 11 of the Fish and Wildlife Service vessel HUGH M. SMITH (Fig. 4) which occupied the period August 20 to October 6, 1951. On this cruise the SMITH proceeded southward along meridian 150° W. occupying fishing stations, and returned northward along the same meridian occupying hydrographic stations (Fig. 5). Bathythermograms and zooplankton hauls were taken on both transits. The south-

[1] Cromwell, Townsend: "Circulation in a meridional plane in the central equatorial Pacific." In Press. *Journal of Marine Research.*

[2] In Figure 3 the vectors at the 3° parallels are in accordance with Ekman's theory of the pure wind drift current (Ekman 1905), i.e., the current transport is indicated at one right angle *cum sole* with the generating wind. Ekman's theory is considered to apply 3° from the equator in accordance with a recent paper by Weenink and Groen (on the computation of surface current velocities in the equatorial regions from wind data. *Proc. of Koninkl. Nederl. Akad. van Wetenschappen*, Amsterdam, Ser. B, 55, No. 3, pp. 239-246, 1952) in which they conclude that at ". . . 2 or 3 degrees . . ." and higher latitudes the internal frictional force is small compared to the Coriolis force. Cromwell has discussed completely the assumptions involved in constructing the figure.

bound transit was interrupted for 15 days at 2°N. latitude to occupy an east-west line of fishing stations. These will be omitted from our discussion.[3] The observations on temperature, phosphate, plankton, and tuna are diagramed in Figures 6 and 7.

The upwelling at or very near the equator is evident at the surface from the drop in temperature, and in cross section by the extension to the surface of the water cooler than 26.7°C (80°F) and richer in phosphate than 0.4 microgram atoms per liter. The transport near the surface of the upwelled water northward and southward from the equator is evident from the extension of the higher phosphate concentration in both directions from the equator. It is also evidenced by the northward component in the direction of longline drift [4] north of the equator and the southward component when they were fished south of the equator (Fig. 6B).

The movement of the water in surface layers toward the north away from the equator decelerates and may terminate. In either event there is convergence and probably sinking. The northern limit of the convergent zone was at 4°50′N. latitude at the time of the northbound passage of the SMITH and is clearly marked by the abrupt change in surface temperature at that latitude (Fig. 7A). This also approximates the southern boundary of the countercurrent. A month earlier, during the southbound passage, this feature was about one degree farther south judging from the change in slope of the 15.6° and 26.7°C isotherms and from the drift of the longline gear (Figs. 6A and B).

Yellowfin tuna were markedly concentrated between the equator and the northern limit of the convergence, the catch averaging four times as many fish per unit of fishing effort between 1° and 6°N. as elsewhere (Fig. 6D).

In the sequence of events between the enrichment of the water at the equator and the production of food for the tuna, several trophic levels intervene. According to stomach examinations tuna eat practically all but the largest members of the bathypelagic nekton, small fish and squid forming their main diet. The fish and squid feed on other nekton or on the zooplankton, which in turn feeds on phytoplankton. Time must intervene and transport of the biota takes place between enrichment of the surface waters and the production of feed for the tuna.

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[3] They are reported by Murphy and Shomura: "Longline fishing for deep-swimming tunas in the central Pacific, 1950-51." Department of the Interior, Fish and Wildlite Service, Special Scientific Report: Fisheries No. 98, May 1953.

[4] The longline fishing gear is a system of horizontal and vertical lines suspended from the surface by buoys. It is allowed to drift freely in the water during the fishing operation, which occupies most of the daylight hours. The drift of this gear is mainly determined by the movement of the upper 100- to 150-meter stratum of water, though it is also influenced somewhat by surface wind and waves. The gear usually drifts far enough for its course and direction to be determined by celestial navigation.

Therefore it is not surprising to find the tuna feeding ground displaced from the upwelling area in the direction of movement of the water in the meridional plane. However, it would be expected that the plankton, occupying an intermediate trophic level, would also occupy an intermediate geographic position. This it does according to some of our other sets of data for trans-equatorial sections. But preponderantly the peak of zooplankton abundance lies closer to the upwelling area than to the fish concentration and sometimes, as in the SMITH Cruise 11 example, it almost coincides with or even lies slightly south of center of upwelling, while the tuna are located well north of it.

This may not be as anomalous as it appears at first sight. Our plankton catches are proportional to the standing crop. The standing crop, in turn, is the product of inter-action between replenishment and losses from mortality, including particularly consumption by other forms in a given water mass. As a consequence the plankton concentration should everywhere be lower than at its center of production, which in the present instance appears also to be the center of upwelling. Simultaneously with the drift of plankton away from the production center and its decline in abundance, it is passing through successional forms, some of them being successive stages in development of individuals, others being successive stages in a food chain. If we may postulate that particular successional forms of zooplankton are required by the particular nektonic forms which constitute forage for the tuna then we have an explanation for the displacement of tuna away from the center of plankton production. Unfortunately we have not yet learned how to sample quantitatively the nekton of tuna-forage size or to learn its feeding habits, and this explanation remains conjectural.

North of the concentration of tuna in the convergence zone lies the equatorial countercurrent marked by elevated surface temperature, upward tilting from south to north of the thermocline (Figs. 6A and 7B) and the eastward drift of longlines (Fig. 6B). Here the surface layers are poor in phosphate (Fig. 7C) and the zooplankton catches are also poor (Figs. 6C and 7B). However, near the northern boundary of the countercurrent, the upper portion of the thermocline, roughly located by the 26.7°C (80°F) isotherm, lies only 50 meters below the surface and water from the thermocline layer might occasionally be stirred by the wind into the overlying warm layer. Possibly such stirring accounts for the distribution of properties found by the Carnegie as depicted by Sverdrup, Johnson, and Fleming ("The Oceans", Fig. 198, p. 710) and interpreted by them to indicate upwelling at the northern boundary of the countercurrent. Some of our hydrographic sections contain indications of enrichment at this location, but the indications

are feeble and do not appear regularly as should be true if upwelling at the northern boundary of the countercurrent were a fundamental part of the circulation.

The surface upwelled water immediately south of the equator may move northward across the equator or it may move southward away from the equator depending on wind direction. At the time of SMITH Cruise 11, the phosphate values, the temperatures, and the plankton catches suggest that it was moving southward away from the equator. There is no evidence of convergence and indeed Cromwell's model calls for none south of the equator unless winds blow from the north as well as from the east. Without convergence, the biota produced in the water drifting south from the center of divergence, upwelling, and enrichment may simply disperse without producing concentrations of tuna such as appear in the convergent zone north of the equator.

However, good catches of albacore taken by our research vessels on several occasions between 5° and 17°S. latitude, suggest that the southward drifting biota may not always completely disperse before high trophic levels are reached.

We may conclude from our examination of the distribution of physical, chemical, and biological properties of sea water in the meridional plane across the equatorial current system at 155°W. longitude: (1) divergence at the equator is induced by easterly winds; (2) upwelling associated with the divergence brings inorganic nutrient salts to the surface layers; (3) plankton develops in the enriched water; (4) the enriched water bearing the plankton moves away from the equator; (5) convergence may occur either north or south of the equator depending on the meridional component of the wind direction; (6) with a northward meridional component, as in southeast trade winds, the convergence is north of the equator; (7) enhanced productivity resulting from equatorial divergence, coupled with the concentrating effect of convergence on the biota as it passes through the successive trophic levels, provides a feeding ground for tuna in the convergent zone; (8) yellowfin tuna concentrate abundantly on this feeding ground.

Turning away from the meridional aspect and remembering that the divergence-convergence system described above will be most effective when there is a strong, steady wind of long reach from an easterly direction, we may examine the east-west distribution of elements pertinent to equatorial productivity. In August, when southeast trade winds are best developed over the equator, the wind conditions for divergence and upwelling are at their best in the eastern half of the Pacific as may be seen from Fig. 8A. Arrows representing wind vectors are shown for the tier of five-degree squares lying on each side of the equa-

tor. These are drawn proportional to the weighted mean resultant travel of the wind. The arrows are longest and travel most nearly from the southeast between 100° and 150°W. longitude. Farther west they lose much of their strength and most of their northward component.

Note also that the winds themselves are divergent in the eastern part of the Pacific and become convergent in the western half. The effect of this equatorial wind divergence on the water has not been studied by oceanographers as far as I am aware. In the absence of a deflecting force at the equator and assuming there is no pressure gradient, the transport of the water should be in the direction of the wind and the wind divergence itself should produce water divergence at the sea surface along the equator east of 180° (and convergence west of 180°). It is not known how strong this effect may be, but any divergence induced directly in this manner should reinforce and strengthen the divergence caused by the forces considered in Cromwell's model.

The east-west trend of plankton abundance is consistent with the results expected from the pattern of the equatorial winds. As shown in Fig. 8B the better catches were made east of 150°W. longitude and there is a decided decline from there toward the west. However, to gain enough material to plot plankton by latitude we have had to combine all seasons of the year over an arbitrary span of latitude and we cannot rely on these data to faithfully show the finer details of plankton distribution.

Similarly the material on yellowfin tuna is not sufficient to consider August alone as was done with the wind data. In Fig. 8C, however, the combined results of a group of fishing cruises during the months of July to November are charted with shading proportional to the catching rate. As expected from the meridional aspect of equatorial circulation the center of abundance is displaced northward from the equator and as expected from the fact that the divergence-convergence structure is contained within the westward flowing South Equatorial Current, it is also displaced to the west of maximum divergence as judged from wind pattern and plankton concentration. The relatively small displacement northward is consistent with the relatively weak meridional circulation and the large displacement westward is consistent with the very much stronger zonal circulation.

In assembling the above materials bearing on equatorial productivity and on the mechanisms involved, I have been highly selective. In part this selectivity has been purposeful and intended to emphasize the major elements of the productivity system. In part the selectivity has been imposed by incompleteness of available information. It should be noted particularly that the meridional aspect was portrayed by a

specific example, and zonal aspect by averages exemplifying a particular period of the year. For neither aspect have I indicated the variability in location and magnitude of the various elements of the system. Likewise there are neglected the peculiarities which crop up in each set of data collected. This portrayal therefore is certainly much distorted in the direction of over-simplification and most probably distorted to an unknown degree in the direction of specific peculiarities of the particular sets of data employed. When more complete data are at hand and when there has been a more thorough study, a different and probably more complex concept will be necessary.

In the meantime there appears to be very complete agreement in the gross features of equatorial circulation, of plankton distribution, and of fishing ground location as to time, place, and relative magnitude. The correspondence is such as to leave little doubt that the yellowfin tuna stock south of Hawaii owes its existence to and is nourished by the equatorial current system.

Perhaps of interest equal to the facts themselves is the demonstration that a rich fishing ground may be discovered through the scientific study of the particular features of ocean circulation pertinent to the existence of fish stocks.

It is, of course, obvious that the attainment of the present degree of understanding has resulted from the participation of a considerable number of persons ranging in specialization from expert fishermen to senior scientists united in a concerted drive toward a common objective. Milner B. Schaefer, John L. Kask, and Donald L. McKernan have successively led the scientific team. Townsend Cromwell, until recently, has been in charge of the oceanographic program; Joseph E. King has been the chief researcher on plankton and on the food of tuna; while Fred C. Cleaver initiated, and Garth I. Murphy has carried on, the longline fishing surveys. I am especially grateful to our present oceanographer, Thomas S. Austin, for invaluable assistance in assembling the materials for this report.

ILLUSTRATIONS

FIGURE 1.—Hydrographic stations occupied by the U.S. Fish and Wildlife Service vessel HUGH M. SMITH for the investigation of equatorial circulation, January 1950 to February 1953.

FIGURE 2.—Longline fishing stations occupied by the U.S. Fish and Wildlife Service vessels HUGH M. SMITH, JOHN R. MANNING, and CHARLES H. GILBERT, and the M/V CAVALIERI (chartered) for investigating the distribution of tuna, October 1950 to March 1953.

FIGURE 3.—Direction of current transport (Small solid arrows), which would exist near the equator under various wind conditions, were there no pressure gradient force acting. The current magnitude is drawn everywhere constant (small solid arrows). For each wind condition (large solid arrows) the meridional components of the current transport (dotted arrows) are drawn to emphasize the regions of meridional divergence (Div.) and convergence (Conv.). From Cromwell's ms. Figure 6.

FIGURE 4.—The Fish and Wildlife Service research vessel HUGH M. SMITH, a tuna-clipper type to which have been added laboratory, winches, and other special instruments for oceanographic research.

FIGURE 5.—Location of the hydrographic and the fishing stations of HUGH M. SMITH Cruise 11, August 20 to October 6, 1951.

FIGURE 6.—Diagrams of certain data resulting from the southbound passage on HUGH M. SMITH Cruise 11 along the 150th west meridian, August 24 to September 25, 1951. A. Temperature section showing the water layer warmer than 26.7°C (unshaded), between 26.7°C and 15.6°C (shaded) and colder than 15.6°C (black), as taken from bathythermographs. B. Direction of drift of longline gear at each fishing station. C. Volume of zooplankton taken in a plankton net of one meter in diameter at the mouth and towed obliquely for approximately one-half hour through the upper 200 meters of water in the daytime. Volumes were measured by displacement and adjusted to a standard quantity of 1000 cubic meters of water strained based on flow determined by a current meter installed in the mouth of the net. D. Rate of catching yellowfin in number per hundred hooks per day fishing as determined by fishing 40 baskets of gear each comprised of 210 fathoms of longline suspended by 10-fathom floatlines and bearing 6 hooks spaced 30 fathoms apart and suspended by 10-fathom droppers.

FIGURE 7.—Diagrams of certain data resulting from the northbound passage on HUGH M. SMITH Cruise 11 along the 150th west meridian, September 25 to October 4, 1951. A. Temperature at the sea surface. B. Temperature section showing the water layer warmer than 26.7°C (unshaded), between 26.7°C and 15.6°C (shaded) and colder than 15.6°C (black), as taken from bathythermographs. C. Phosphate section showing water with less than 0.4 microgram atoms per liter (unshaded) between 0.4 and 1.0 microgram atoms per liter (shaded) and more than 1.0 microgram atoms per liter (black). D. Volume of zooplankton taken and treated as stated in the title of Figure 6, except that the hauls were made at various hours of the day and night and received further adjustment for diurnal variation according to the formula: V_a = antilog

(log V + 0.1 sin t) where V_a is the adjusted volume, V the unadjusted volume, and t the angle of rotation of the hour hand on the 24-hour clock at the time of the mid-point of the hauling period, with zero rotational angle such that the angle whose sine is 1.0 occurs at midnight and —1.0 at noon.

FIGURE 8.—Diagram of wind vectors, plankton abundance, and tuna distribution in the equatorial zone. A. Resultant wind vectors were computed as the weighted means of frequency and speed from the several compass points for 5-degree squares bordering the equator as published in U.S. Hydrographic Office Pilot Chart for the North Pacific for August 1952, the arrows point in the direction of travel and their shafts are proportional to the weighted mean speed. B. Mean plankton volumes at several longitudes computed as the mean of all hauls taken from between latitudes 5°S to 10°N at or near the given longitude. C. Distribution of yellowfin tuna in the mid-Pacific equatorial region as estimated from longline catches. The lightest stipling represents less than 3 yellowfin tuna per hundred hooks, the heaviest represents more than 9 per hundred hooks and the intermediate stipling represents intermediate catching rates. For orientation as to location and area there is given by light stipling the area of the Japanese prewar longline fishery and by dashed outline the area of the American west coast live bait and purse seine fishery for yellowfin and skipjack tunas.

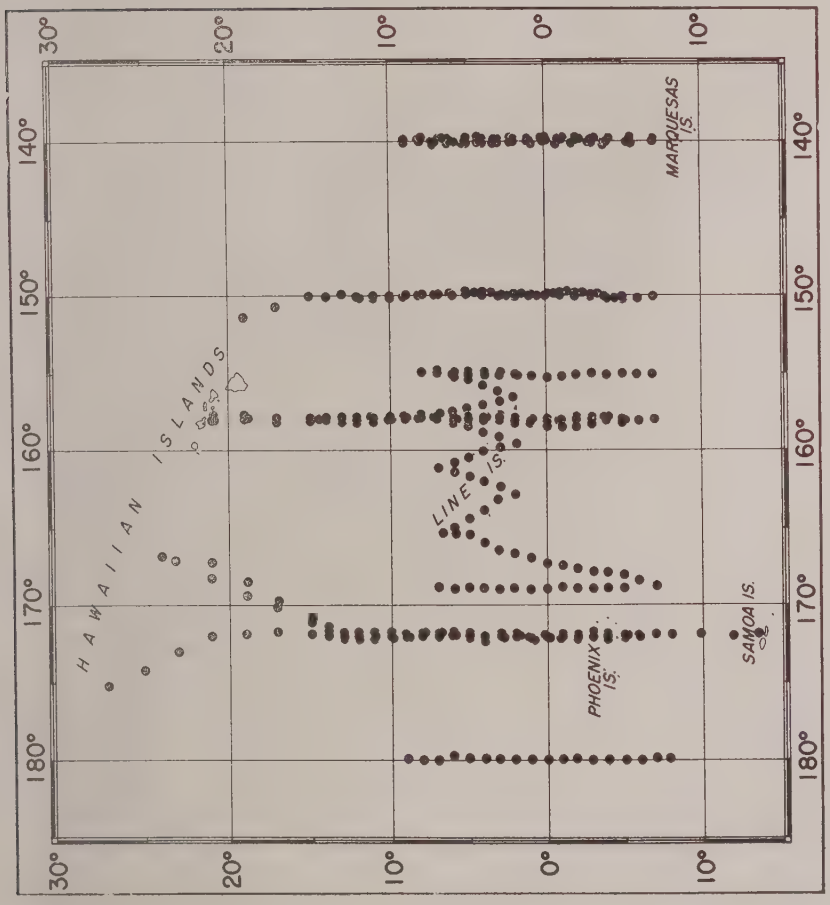
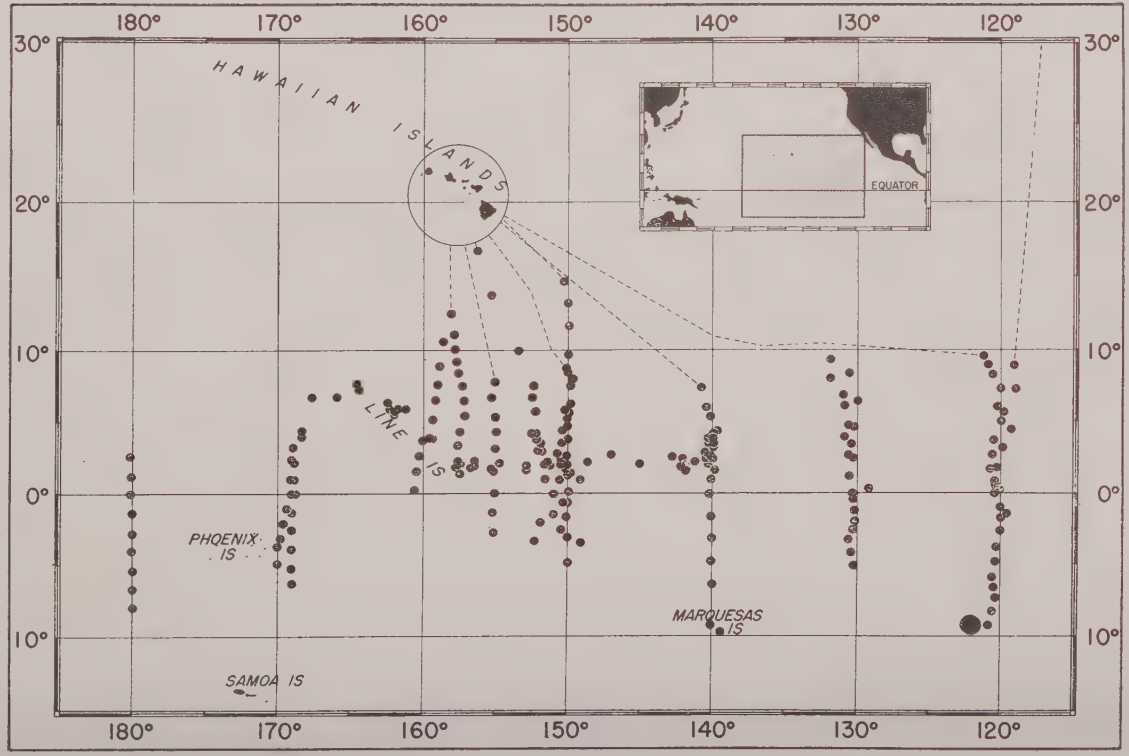

30°
20°
10°
0°
10°
140°
150°
160°
170°
180°
HAWAIIAN ISLANDS
LINE IS.
PHOENIX IS.
SAMOA IS.
MARQUESAS IS.

FIGURE 1



EQUATORIAL LONGLINE FISHING CRUISES

FIGURE 2

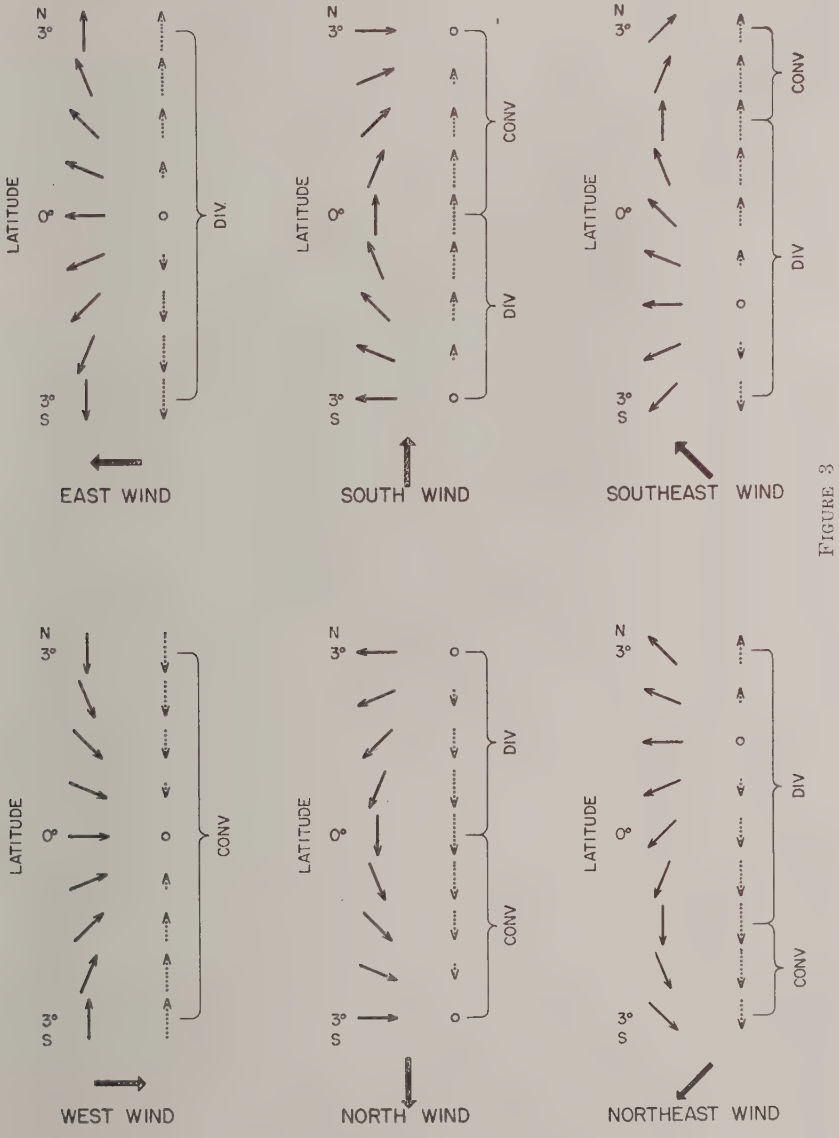

LATITUDE
N 3°
0°
3° S
DIV
CONV
EAST WIND
SOUTH WIND
SOUTHEAST WIND
WEST WIND
NORTH WIND
NORTHEAST WIND

FIGURE 3

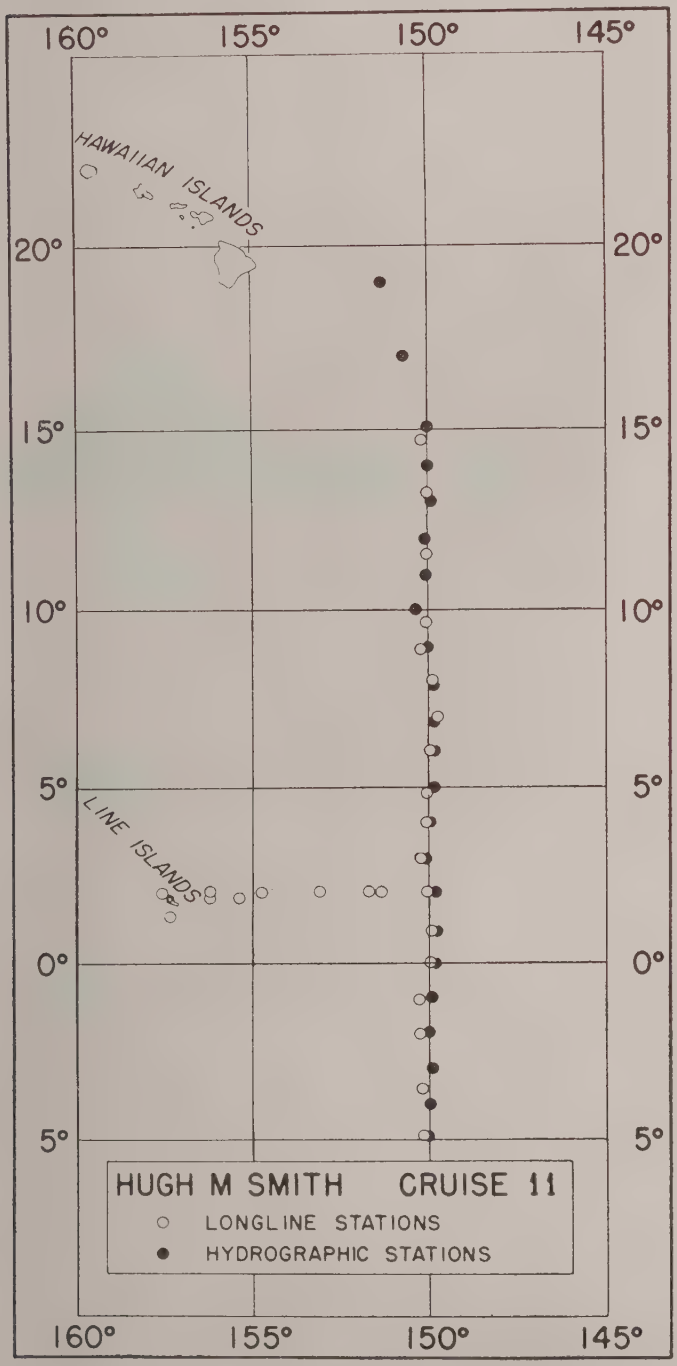

160°
155°
150°
145°
HAWAIIAN ISLANDS
20°
15°
10°
5°
0°
5°
LINE ISLANDS
HUGH M SMITH CRUISE 11
LONGLINE STATIONS
HYDROGRAPHIC STATIONS

FIGURE 5

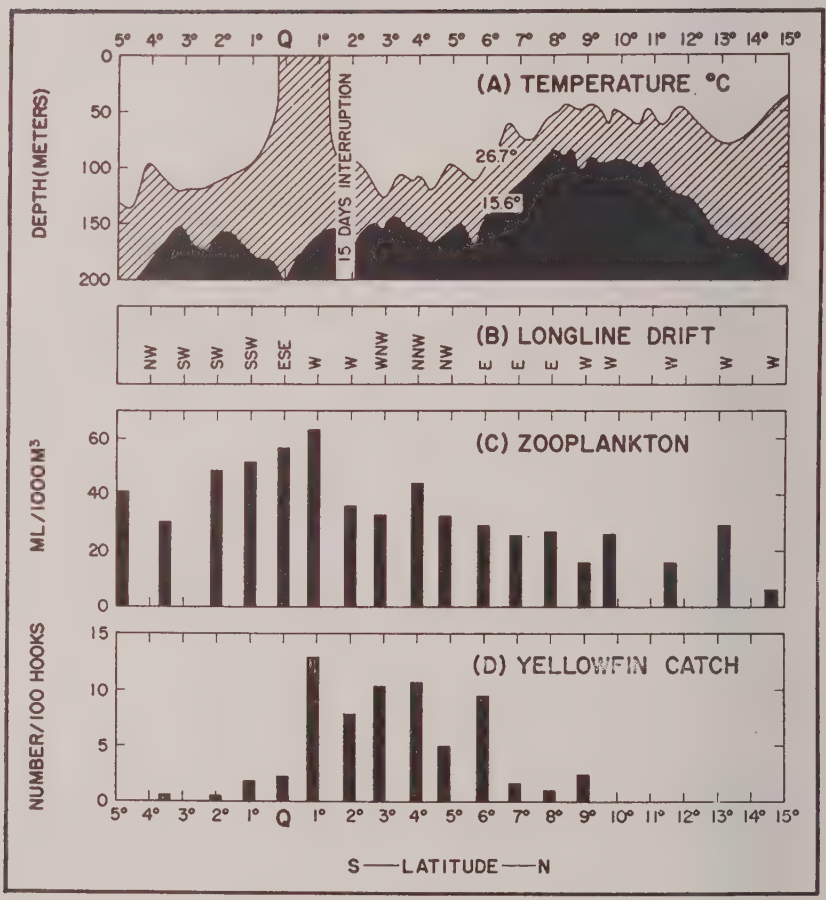

5° 4° 3° 2° 1° Q 1° 2° 3° 4° 5° 6° 7° 8° 9° 10° 11° 12° 13° 14° 15°
DEPTH (METERS)
0
50
100
150
200
(A) TEMPERATURE °C
26.7°
15.6°
15 DAYS INTERRUPTION
(B) LONGLINE DRIFT
NW SW SW SSW ESE W W WNW NNW NW E E E W W W W W
ML/1000M³
60
40
20
0
(C) ZOOPLANKTON
NUMBER/100 HOOKS
15
10
5
0
(D) YELLOWFIN CATCH
5° 4° 3° 2° 1° Q 1° 2° 3° 4° 5° 6° 7° 8° 9° 10° 11° 12° 13° 14° 15°
S——LATITUDE——N

FIGURE 6

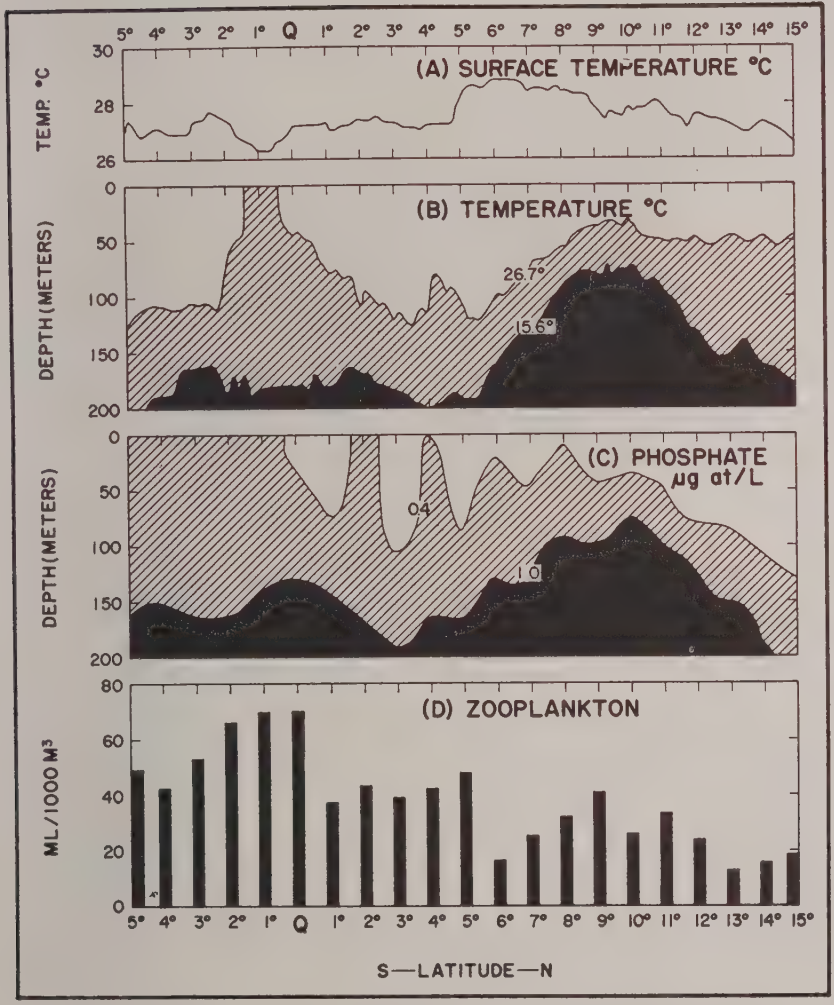

5° 4° 3° 2° 1° Q 1° 2° 3° 4° 5° 6° 7° 8° 9° 10° 11° 12° 13° 14° 15°
TEMP. °C
30
28
26
(A) SURFACE TEMPERATURE °C
DEPTH (METERS)
0
50
100
150
200
(B) TEMPERATURE °C
26.7°
15.6°
DEPTH (METERS)
(C) PHOSPHATE
µg at/L
0.4
1.0
ML./1000 M³
80
60
40
20
0
(D) ZOOPLANKTON
S—LATITUDE—N

FIGURE 7

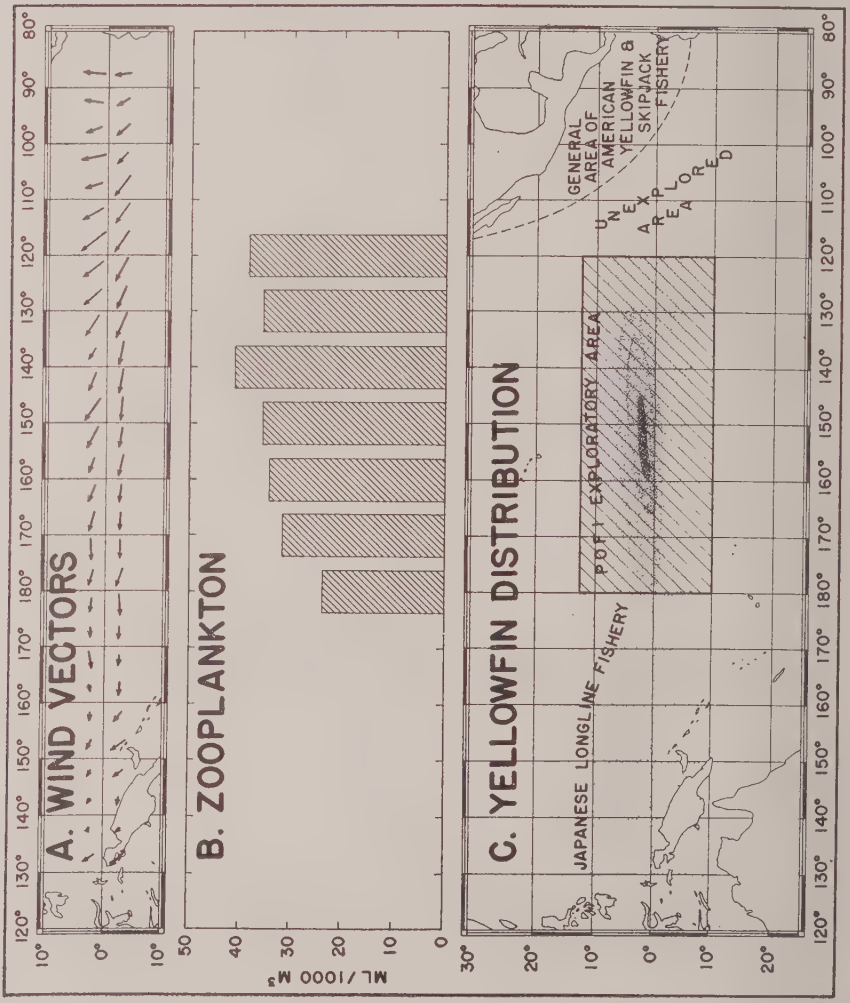

A. WIND VECTORS
B. ZOOPLANKTON
ML/1000 M³
C. YELLOWFIN DISTRIBUTION
JAPANESE LONGLINE FISHERY
POFI EXPLORATORY AREA
UNEXPLORED AREA
GENERAL AREA OF AMERICAN YELLOWFIN & SKIPJACK FISHERY

FIGURE 8

AN EPIZOOTIC IN GULF OF SAINT LAWRENCE FISHES

CARL J. SINDERMANN

U. S. Fish and Wildlife Service, Boothbay Harbor, Maine

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AN EPIZOOTIC IN GULF OF SAINT LAWRENCE FISHES

Carl J. Sindermann
U. S. Fish and Wildlife Service, Boothbay Harbor, Maine

Accounts of mass mortalities of marine fishes are not uncommon in scientific literature and the popular press, but few of these catastrophes have been definitely associated with a specific pathogen. An outstanding exception is found in sea herring (*Clupea harengus*) of the western North Atlantic, which have been known for almost half a century to be subject to periodic epizootics of a systemic fungus disease caused by *Ichthyosporidium hoferi*. The most recent outbreak occurred in the late spring and summer of 1954 and 1955 and to a lesser extent in 1956. During this period large numbers of herring died in the Gulf of Saint Lawrence from effects of the disease. During the same period, less extensive mortalities of alewives (*Pomolobus pseudoharengus*) and mackerel (*Scomber scombrus*) were reported from the same locality. The area encompassed by the herring mortalities was so extensive, and the numbers of fish involved were so great that studies were made by biologists of the Fisheries Research Board of Canada, the Department of Fisheries of the Province of Quebec, and the United States Fish and Wildlife Service. Several papers and reports have already appeared on aspects of this outbreak and resulting mortalities (Leim 1955, 1956; Sindermann 1956, 1957; and Templeman 1954). It is the purpose of this report to continue the documentation of this period, insofar as herring and certain other commercially important species are concerned. Effects on the fishery of the region seem quite marked, and rather clearly related to the disease outbreak. Although a complete analysis of the total ecological effect of the fungus epizootic must await several further years of observation and greater perspective, a summary of descriptive and experimental data obtained during the outbreak period seems warranted now.

Mortalities of Sea Herring During the Period 1954-1956

Widespread herring mortalities, particularly of mature spring-spawning fish, were first reported from the Gulf of Saint Lawrence in late spring and early summer of 1954 (Tibbo, unpublished data[1]). Dead fish were observed floating in shoals at the surface, were washed up on the shores of the Gulf, and were taken in nets of otter trawlers. Mortalities extended from the west coast of Newfoundland to the

[1]Typewritten report by S. N. Tibbo dated August 16, 1954, to the director of the Biological Station, St. Andrews, N. B. A copy of this report was made available to the author by Mr. Tibbo.

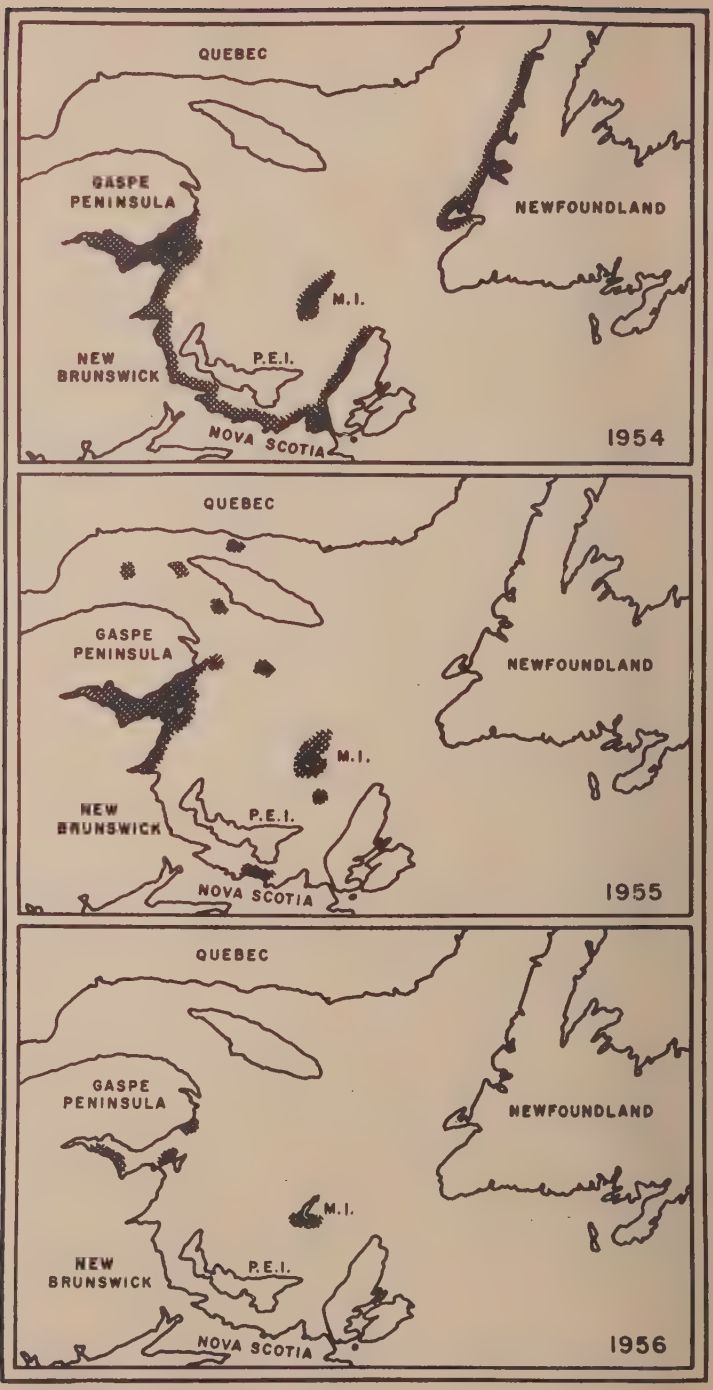

Figure 1. Locations of observed or reported mortalities of sea herring.

Gaspe coast, and from Anticosti Island to Northumberland Strait. Deaths were first apparent in mid-May, reached a peak in June, continued at a reduced rate through July, and apparently ceased in August. Abnormal, lethargic, moribund herring could be seen inshore, particularly near breakwaters, throughout the period. Deaths occurred sporadically in such inshore aggregations, the dying fish sinking to the bottom to become part of an extensive litter of herring carcasses. This pattern was repeated in 1955 as far as numbers of fish, abnormal behavior, and time were concerned. Mortalities in 1956 were drastically lower, being confined to the Chaleur Bay region and the Magdalen Islands, and to relatively few fish as compared to 1954 and 1955. No dead herring were found in 1957. Areas in which mortalities were observed and reported in each of the three years are indicated in Figure 1.

Wherever examined, dead fish were found to be infected with the fungus *Ichthyosporidum hoferi.* This pathogen causes systemic infection, with foci in the heart (Figure 2) and lateral line musculature. The disease affects fish of all ages and is probably acquired in in-

Figure 2. Hearts of normal (left) and fungus infected herring. Photograph by Mr. Paul Montreuil, Director, Marine Biological Laboratory, Grindstone, Magdalen Islands.

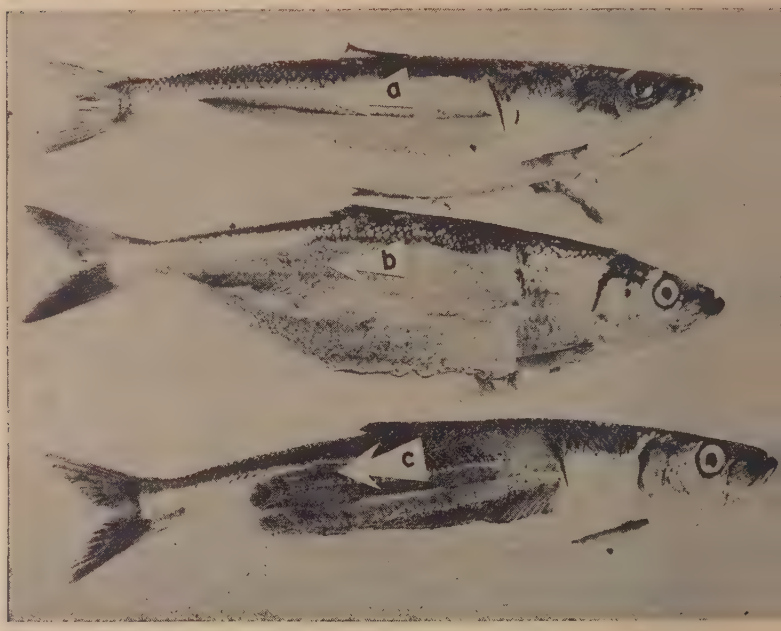

Figure 3. Lateral line musculature of mature herring. (a) uninfected, (b) acute infectio with necrosis, and (c) chronic infection with pigmentation. Photograph by Mr. Paul Montreui Director, Marine Biological Laboratory, Magdalen Island.

shore areas. The causative organism has been experimentally trans mitted directly from fish to fish (Sindermann and Scattergood 1954) Death of diseased fish seems due to circulatory failure in most cases although massive involvement of organs other than the heart may b contributory. From examination of the course of the disease in 195 and 1956, and from experimental work conducted during that period it appears that the initial and extensive mortalities were caused by a acute phase of the disease, characterized by rapid massive fungus in vasion of susceptible fish. Experimentally, this type of infection wa terminal within one month from time of exposure. Acute infections in addition to killing many fish, caused degeneration and necrosis o the body muscles, particularly the lateral line musculature (Figur 3b). Such diseased fish were poor for smoking, because they fell fron smoke-house racks, and were not suitable for pickling, since they wer already partly decomposed. Later sporadic deaths and infections ap parent on gross examination were due principally to a subacute o chronic phase, characterized by marked host cellular response, in fis

apparently more resistant to the disease organism. Abundant infections, principally of this type, were characteristic of late summer and autumn, after mass mortalities had apparently ceased. These infections were often accompanied by pigment deposition around fungus spores in the body muscles (Figure 3c), creating an additional problem for herring picklers.

Sampling in 1955 and 1956 disclosed a low disease incidence in the earliest (late April) run of herring, indicating that few heavily infected fish survived from the previous year. Coincident with first reports of mortalities, a rapid rise in incidence, especially of acute infections, occurred in late May, one month after the herring appeared inshore.

From observations made in 1955 it was estimated conservatively that at least one-fourth of the mature herring of the western Gulf were affected in that year (Sindermann 1956); this was later supported by the fact that herring landings for the entire Gulf in 1956 decreased one-third from the 1955 landings. There was no evidence that fishing effort had decreased during 1956. Mortalities in some Gulf areas in 1954 were at least as severe as in 1955, suggesting significant population decimation as a result of this outbreak; this was supported by the fact that Chaleur Bay landings, compared to the average for the

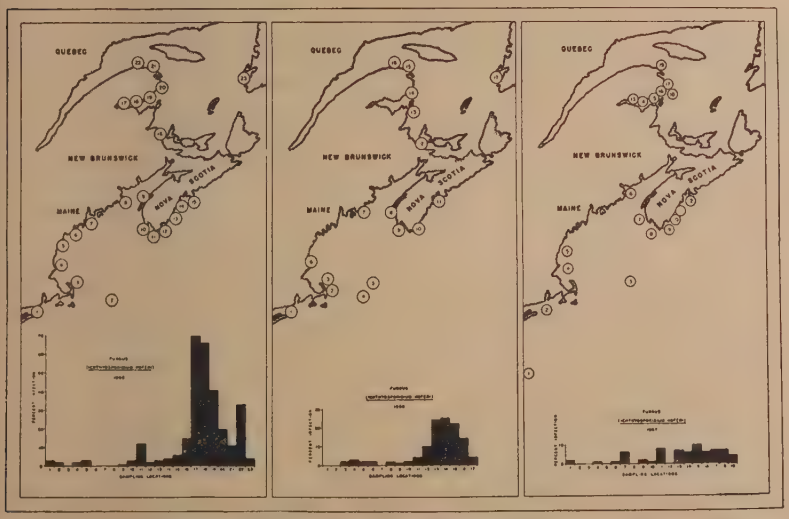

Figure 4. Fungus incidence in samples of mature herring of the western North Atlantic, comparable in location and time for 1955, 1956 and 1957.

previous ten years, were in 1955 only 74 per cent, and in 1956 only 62 per cent, and were lower than any other single year in the previous ten. Indications at present are that the 1957 catch was even lower.

Since mortalities in 1956 were greatly reduced, that year may be considered the first post-epizootic year. Disease incidence in the Gulf, except at the Magdalen Islands, was lower in 1956 than in 1955, and was much lower in 1957 than in 1956. Incidence averaged 27 per cent in 1955, 22 per cent in 1956 and 10 per cent in 1957. Fungus incidences in herring sampled in these years are graphed in Figure 4. Although not included in the graphs, it should be noted that early autumn incidences in the Gulf of Saint Lawrence were as high or higher than spring-early summer figures. For example, two September samples from Chaleur Bay in 1957 had incidences of 24 and 30 per cent, much higher than the spring-early summer average of 6 per cent. Also, one sample of trawled herring from the Magdalen Islands in 1957 had an incidence of 78 per cent, possibly representing a differential deeper-water aggregation of infected fish.

This fungus disease is enzootic in western North Atlantic herring stocks, and is characterized by periodic outbreaks in the Gulf of Maine and the Gulf of Saint Lawrence. It was first reported from Gulf of Saint Lawrence herring by Cox (1916) after an epizootic and mortalities in 1913-1914. According to that investigator, a similar outbreak had occurred in the Gulf of Saint Lawrence in 1898. The next reported outbreak occurred in 1930-1931 in the Gulf of Maine (Daniel, 1933a and 1933b; Fish, 1934) among immature herring. Another outbreak in the Gulf of Maine occurred in 1947 (Scattergood, 1948), also among immature herring. Both of the Gulf of Maine epizootics were characterized by widespread fungus infections but no reported mortalities such as those which occurred in the Gulf of Saint Lawrence. The outbreak of 1954-1956 thus constitutes the fifth to be recorded among herring of the western North Atlantic during the past 60 years.

EXPERIMENTAL STUDIES

The outbreak period in the Gulf of Saint Lawrence was a time of very low disease incidence in Gulf of Maine herring. This offered an admirable opportunity to examine the disease in contrasting phases, and to supplement descriptive studies with experimental work using a susceptible population. Immature Gulf of Maine herring, maintained in the sea water tanks of the Boothbay Harbor Fisheries Laboratory, were used in all experiments. Data have been obtained on fungus virulence, infective dose, possible methods of transmission, host resistance, and duration of infection. This information will be presented in detail in a later paper, but may be summarized as follows:

(1) The disease can be transmitted by feeding spores removed from infected fish. Exposure of 50 age-group-1 herring to 2 x 10^5 spores in a single dose resulted in no infection, but the same dose given on two successive days to another experimental group of 50 fish resulted in infections in four (eight per cent).

(2) Experimental groups of 50 age-group-1 herring fed increasing numbers of fungus spores (above the dosage in (1) above) exhibited increasing incidence of infections of the subacute or chronic type up to a certain level of dosage (usually 4 exposures to 2 x 10^5 spores on 4 successive days); above this, acute infections and mortalities also occurred.

(3) Acute infections occurred in experimental fish within one month from time of exposure to a sufficiently large number of spores. These infections were characterized by massive invasion of the heart and necrosis of tissue adjacent to spores, with little host cellular response. Subacute or chronic infections, characterized by pronounced host cellular response, occurred after one month from time of exposure. Such infections were progressive and terminal in most experimental fish, while in a few they persisted for 18 months.

(4) An experimental epizootic, produced in 2000 age-group-0 herring by exposure on four successive days to doses of 2 x 10^5 spores each, resulted in infection of 23 per cent of the population—8 per cent acute and 15 per cent subacute. The disease was terminal in all but light chronic cases within three months. Mortalities from acute infections occurred from 14 to 30 days, and from heavy chronic infections after that time. Control fish were entirely negative for the disease throughout the experiment.

(5) From percentage of infections obtained, age-group-0 herring appeared to be more susceptible to identical dosages of spores than age-group-1 or age-group-2 fish.

(6) The fungus organism from Gulf of Saint Lawrence herring was similar to that from Gulf of Maine herring in its effects on experimental fish. Fungus organisms from the two Gulfs did not differ in culture morphology or growth rate.

When experimental results are related to observations of the outbreak in nature and to previous studies, a somewhat coherent picture of the disease in epizootic form begins to emerge, although there are still large gaps in our knowledge. It does appear that infection pressure and host susceptibility play major roles here, as they have been found to do in other epizootics and epidemics.

ECOLOGICAL IMPLICATIONS OF THE DISEASE OUTBREAK

The Gulf of Saint Lawrence herring population has been decimated by this disease outbreak, although effects may be transient. Combining experimental findings with field observations of the extent of mortalities, with disease incidence disclosed by sampling, and with catch statistics, it may be estimated conservatively that at least half the mature herring of the Gulf were destroyed during the outbreak period 1954-1956. According to Cox (1916) the herring catch in the Gulf was reduced for several years following the 1913-1914 mortalities. Outbreaks of the same disease in Gulf of Maine herring in 1930-1931 and in 1947 were not accompanied by observed mortalities, and the fishery did not seem to be immediately affected. However, this fishery concentrates on herring of the 0 and 1 age groups, which were heavily infected, and it is interesting and perhaps significant that in 1950-1951, when these fish would have contributed to the spawning stocks, there appeared to be a pronounced reduction of the inshore mature herring population of the Gulf of Maine. It should be noted, however, that little is known of offshore spawning populations, so that this apparent reduction might be due to a shifting of spawning grounds. While other interpretations are possible, these limited data, plus observations of the magnitude of the mortalities in 1954 and 1955, tend to support the hypothesis that the fungus disease is an important factor in shaping fluctuations in abundance of herring of the western North Atlantic. Mature as well as immature fish are affected; a significant part of the population is involved during outbreaks; and many of the fish that become infected are killed.

The fungus disease has had both direct and indirect effects on species other than herring in the Gulf of Saint Lawrence. Alewives (gaspereau) and mackerel are known to be susceptible to this fungus organism (Sproston, 1941; Sindermann and Scattergood, 1954). Scattered mortalities of both these species were reported and observed in the Gulf in 1954 and 1955.

The presence of great quantities of dead and dying herring might be expected to affect bottom-feeding animals and scavengers. Examination of the cod and lobster landing statistics for the Gulf of Saint Lawrence, and for Chaleur Bay in particular, gives some indication that this may have been the case. In both 1954 and 1955, the years of heaviest mortalities of herring, lobster catches declined sharply coincident with reports of mortalities—probably because lobsters were feeding on dead herring, and had little reason to enter traps for food. Cox, reporting on the 1913-1914 mortalities, also noted that the lobster

catch, which was above average up to the time the herring began dying, suddenly fell off, and even crabs failed to enter traps.

Cod taken in 1954 and 1955 were frequently found to have herring remains and also the fungus organism in their digestive tracts, suggesting that they were feeding heavily on herring. This was further suggested by the fact that when the herring mortalities began in 1954, the catches of the Gaspe long-line and hand-line cod fisheries deceased sharply, while those of the otter trawl fishery remained unchanged (Ronald, in press). This also agrees generally with the observation of Cox that during the 1913-1914 outbreak cod were found closer inshore than usual, refused bait, but were caught freely in salmon nets, an unusual occurrence. Cod landings in Chaleur Bay, which seemed to be a focus of the disease outbreak in the herring, were in 1956 (the first post-epizootic year) 52 per cent above the average for the preceding eight years, and higher than any single year during this period.[1] Present indications are that the 1957 catch was also exceptionally high. According to Martin (1957), landings of cod in the provinces of Quebec, New Brunswick, and Prince Edward Island in 1956 were the largest on record. Increased landings were due to larger size and not to greater numbers of fish. Individual cod were considerably larger and the growth rate was much higher in 1955-1956 than in the period 1947-1952. Although other factors might be involved, the increase may well be related to the abundance of diseased and dying herring in 1954 and 1955. The relationship of this greater growth of Gulf of Saint Lawrence cod to increased availability of herring was suggested by Martin (1956) and is supported by observations made during the present study and also by Ronald (in press). If such a relationship is real, the outbreak period has positive as well as negative aspects.

The new observations and experimental findings reported here, together with other reports referred to, suggest that this outbreak period was one of great ecological change in the Gulf of Saint Lawrence. Effects may be only temporary, but the important role of epizootic disease in the marine environment has been well illustrated.

Summary

Extensive mortalities of sea herring and lesser mortalities of alewives and mackerel occurred over much of the Gulf of Saint Lawrence in 1954 and 1955, and smaller mortalities in 1956. Wherever examined, such mortalities were found to be associated with systemic infection by the fungus *Ichthyosporidium hoferi,* a pathogen responsible for a similar outbreak in the Gulf of Saint Lawerence in 1913-1914, and with

[1]Comparable cod landing statistics for Chaleur Bay are available only since 1947.

outbreaks in the Gulf of Maine in 1930-1931 and in 1947. Dead herring could be found in 1954 and 1955 floating at the surface, dead on the bottom, and washed up on the shores of the Gulf. The nets of otter trawlers were frequently fouled with dead and decomposing herring from the bottom. Disoriented, lethargic, infected herring could be seen dying in inshore areas during the early summer, after the time when normal fish would have moved offshore following spawning. From sampling done in 1955 it was estimated that one-fourth of the mature spring-spawning herring of the western Gulf were affected during that year alone, with indications of a similar incidence in 1954.

Experimental studies have demonstrated that, depending on host susceptibility and infective dose, the disease may occur in either acute or chronic phases, rapidly terminal in the former and progressively so in the latter. This, combined with field observations of magnitude of mortalities, with disease incidence disclosed by sampling, and with catch statistics, suggests significant herring population reduction as a result of the outbreak.

Changes in the fisheries for other commercially important species of the Gulf of Saint Lawrence, notably cod and lobster, have been related to the epizootic in herring.

ACKNOWLEDGMENTS

The author wishes to express his thanks for the hospitality and assistance of many individuals and organizations during the course of this study, especially Dr. Alexandre Marcotte and Mr. Keith Ronald of the Marine Biological Station, Grande Rivière, P. Q.; Dr. A. H. Leim and Mr. S. N. Tibbo, Biological Station, St. Andrews, N. B.; and Mr. Paul Montreuil and Miss Monique Gauthier, Marine Biological Laboratory, Grindstone, Magdalen Islands. Members of the staff of the Fisheries Laboratory, Boothbay Harbor, Maine, assisted with field observations and collections. The manuscript was reviewed by Mr. L. W. Scattergood, Mr. B. E. Skud, and Dr. A. H. Leim.

LITERATURE CITED

Canada, Dominion Bureau of Statistics, Monthly Reports of Production Statistics, 1947-1956.

Cox, P.
1916. Investigations of a disease of the herring (*Clupea harengus*) in the Gulf of Saint Lawrence. Contrib. Can. Biol. 1914-1915: 81-85.

Daniel, G.
1933a. Studies on *Ichthyophonus hoferi*, a parasitic fungus of the herring (*Clupea harengus*). I. The parasite as it is found in the herring. Am. J. Hyg. 17: 267-276.

———.
1933b. Studies on *Ichthyophonus hoferi*, a parasitic fungus of the herring (*Clupea harengus*). II. The gross and microscopic lesions produced by the parasite. Ibid. 17: 491-501.

Fish, F.
1934. A fungus disease in fishes of the Gulf of Maine. Parasitol. 26: 1-16.

Leim, A.
1955. Herring mortalities in the Bay of Chaleur in 1955. Fish. Res. Bd. Can., Prog. Repts. Biol. Sta. Atlantic No. 62: 30-32
———.
1956. Herring mortalities in the Gulf of Saint Lawrence, 1955. Fish. Res. Bd. Can. Manuscript Repts. Biol. Sta. No. 607: 1-9.
Martin, W.
1956. Change in growth of Gulf cod. Fish. Res. Bd. Canada, Ann. Rept. Biol. Sta. 1956: 63-66.
———.
1957. Canadian Researches: High Cod Landings. International Commission for the Northwest Atlantic Fisheries, Annual Proceedings 7: 25.
Quebec, Bureau of Statistics, Preliminary Annual Reports of the Maritime Fisheries, 1947-1956.
Ronald, K.
(in press) Herring mortalities in the coastal waters of the Gaspe Peninsula. Report to the Minister of Fisheries of the Province of Quebec for 1954.
Scattergood, L.
1948. A report on the appearance of the fungus *Ichthyosporidium hoferi* in the herring of the northwest Atlantic. U. S. Fish and Wildlife Ser., Spec. Sci. Rept. No. 58: 1-33.
Sindermann, C.
1956. Diseases of fishes of the western North Atlantic. IV. Fungus disease and resultant mortalities of herring in the Gulf of Saint Lawrence in 1955. Maine Dept. Sea and Shore Fish., Res. Bull. No. 25: 1-23.
———.
1957. Mass mortalities of marine fishes in the Gulf of St. Lawrence 1954-1956. Anat. Rec. 128: 622.
——— and L. Scattergood
1954. Diseases of fishes of the western North Atlantic. II. Ichthyosporidium disease of the sea herring (*Clupea harengus*). Maine Dept. Sea and Shore Fish., Res. Bull. No. 19: 1-40.
Sproston, N.
1944. *Ichthyosporidium hoferi* (Plehn and Mulsow 1911) an internal fungoid parasite of mackerel. J. Mar. Biol. Assoc. (U. K.) 26: 72-98.
Templeman, W.
1954. Herring mortality. Rept. Newfoundland Fish. Res. Sta. for 1954. App. No. 14: 25-26.

DISCUSSION

MR. RAY LANE [Urbana, Illinois]: I did not notice any checking here on post-contamination possibly from soil erosion or perhaps sewage disposal. Has that been ruled out?

DR. SINDERMANN: Not entirely. This is one of the things that was brought up in the Gulf, where there are all kinds of pulp processing plants and so on. Probably the fact that we can reproduce this disease in many of its aspects in our experimental tanks in a completely different environment tends at least to reduce the possibility of this type of effect.

We have investigated the possible role of temperature in these epizootics as far as possible and have found no clear-cut relationship. We are, of course, able to culture this organism and the culture characteristics and effects of culture material seem to be identical to those in the St. Lawrence during the epizootic.

DISCUSSION LEADER FAHY: Dr. Sindermann, on those arrested cases where the fish, presumably your experimental fish, persisted for 18 months, did you notice what might be the expected effect on reproductive organs?

DR. SINDERMANN: In the Gulf of Maine we deal almost exclusively with immature herring and used them in the experimental work. We have little chance of obtaining mature fish, so the effect on reproductive abilities could not be determined. However, we have noticed from sampling in the St. Lawrence, that chronic infections, even heavy ones, do not seem to prevent reproduction. We found heavily infected, chronic type infections, and the fish still seemed to be either ripening or in the process of laying eggs.

MR. WILLIAM H. MASSMAN [Virginia Fisheries Laboratory, Gloucester Point, Virginia]: What other fishes are infected by this fungus?

DR. SINDERMANN: The disease organism shows a remarkable lack of fastidiousness in host selection, since, in addition to herring, flounders, alewives and mackerel

are known to be susceptible. We have experimentally infected killifish and goldfish. European workers know the organism primarily as a pathogen of aquarium and fresh-water fishes—principally salmonids. Fish and Wildlife Service pathologists in the western United States have recently recognized and experimented with a fungus pathogen of trout and salmon that bears a strong resemblance to our beast. The organism has been reported from several genera of calanoid copepods, and we have experimentally infected *Calanus finmarchicus*. We have not, however, found natural infections in plankton collections from the outbreak area. In the Gulf of Maine, infections in alewives seem to parallel those of herring, although incidences in the former are lower. The histological picture of infection in alewives is one of greater host response to the presence of fungus, and external and gross symptoms are also less pronounced than in herring. Herring do seem to be the primary hosts for this parasite in the western North Atlantic, although other species may act as reservoirs.

MR. ROBERT C. HILFIBRAN [State Natural History Survey, Urbana, Illinois]: Do you have any information on the amount or increase of spores during the siege of infectivity and also where did you get the spores that you used in setting up your synthetic infections?

DR. SINDERMANN: We have been able to find spores in bottom sediments in the Gulf of St. Lawrence. We did not get up there early enough to see what the spore condition was before the outbreak. We have been able to keep the spores in sterile sea water at sea water temperatures and they survive from autumn to the following spring with no apparent reduction in viability, at least in terms of cultured germination.

The spores in the herring are infective to other herring. Usually in these experimental exposures, we remove the spores directly from the fish, and they are infective to other fish, although culture material has been tried. The culture growth is so slow and so sparse that it would take extensive preparation to get sufficient spore material. We use large numbers of spores to obtain these infections. Apparently the resistance is high or the infectivity of spores is low. So we need massive doses to obtain experimental infections.

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Page 622

250 Mass mortalities of marine fishes in the Gulf of Saint Lawrence 1954–1956. Carl J. Sindermann, U. S. Fish and Wildlife Service.

Extensive mortalities of sea herring and lesser mortalities of alewives and mackeral occurred over much of the Gulf of Saint Lawrence in 1954 and 1955, and smaller mortalities in Chaleur Bay in 1956. Wherever examined, such mortalities were found to result from systemic infection by the fungus *Ichthyosporidium hoferi,* a pathogen associated with a similar disease outbreak in the Gulf of Saint Lawrence in 1913–1914, and with outbreaks in the Gulf of Maine in 1930–1931 and in 1947. Dead herring could be found in 1954 and 1955 floating at the surface, dead on the bottom, and washed up on the shores of the Gulf. Disoriented, lethargic, infected herring could be seen swimming and dying in inshore areas, especially during the early summer. From sampling done in 1955, it was estimated that one-fourth of the mature spring spawning herring of the western Gulf were infected during that year alone, with indications of a similar incidence in 1954. Since experimental work has demonstrated that the disease is terminal in many cases, significant population decimation has undoubtedly occurred as a result of this outbreak.

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Relation of Adult Pink Salmon Size to Time of Migration and Freshwater Survival

Bernard Einar Skud

THE two-year life span of the pink salmon, *Oncorhynchus gorbuscha* (Walbaum), is climaxed by spawning activities in the fall. The eggs, laid in gravel beds of streams, incubate for 5 to 7 months. In the spring the young work out of the gravel and migrate seaward. Environmental conditions during the period of incubation are

known to affect the freshwater survival but the degree of their influence has not been measured. Studies at Sashin Creek, Little Port Walter, Alaska, indicate that biological as well as environmental factors determine the rate of survival. The purposes of this paper are to show the relationship between adult size and time of spawning and to discuss the possible influence of this relationship on the survival of young in freshwater.

In Southeastern Alaska the spawning migrations begin in late June and continue into October. The races comprising the migrations can be separated readily into two seasonal groups commonly called "early" and "late" runs. The "early" runs characteristically reach their spawning streams in July and August and the "late" runs in September and October. In this paper "early" and "late" runs will be designated July and September runs.

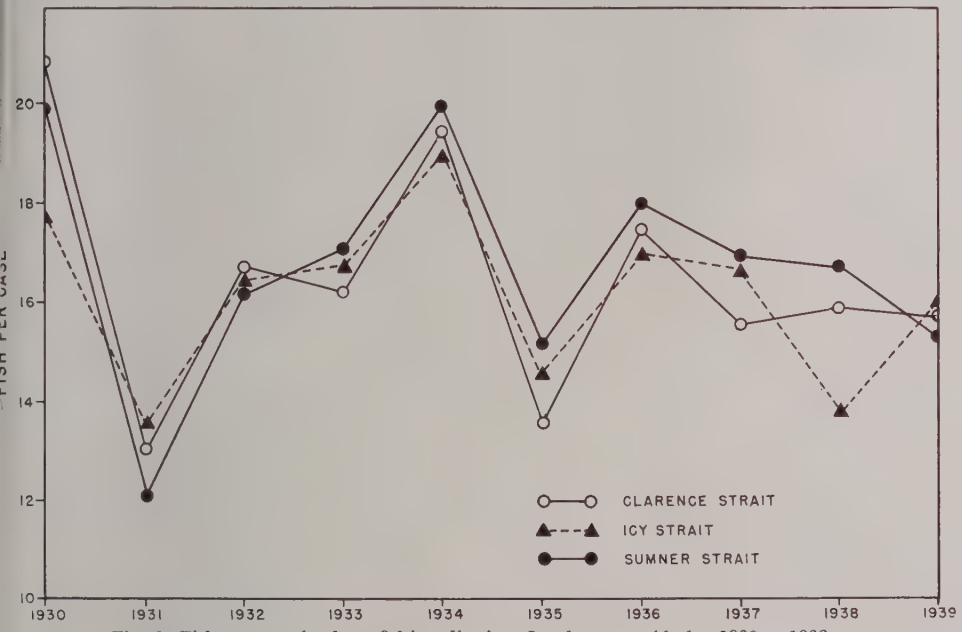

Fig. 1. Fish per case in three fishing districts, Southeastern Alaska, 1930 to 1939.

Size of Pink Salmon at Maturity

At the outset of their seaward migration, the young salmon weigh less than 0.4 grams and rarely attain a length of 40 mm. Over 90% of the growth is made during their oceanic life; the returning adults weigh from 2 to 11 pounds and measure up to 700 mm. (standard length).

The size of adult pink salmon can be determined by measuring individuals in the catch or in spawning runs entering streams and by estimating from the number of fish utilized per case of canned salmon. Though more precise, fish length data from the catch and spawning runs are not always available and do not furnish consecutive years of information needed for this analysis. On the other hand, cannery records do provide comparisons of average fish size for many years. The number of fish per case has ranged from 12 to 24 throughout the years.

This average number of fish per case reveals yearly fluctuations in adult size that are remarkably similar in three distinct fisheries with wide geographic separation in Southeastern Alaska (Fig. 1). Hoar (1951) reported a similar regularity in size fluctuations in the pink salmon fisheries of British Columbia. The simultaneous changes in size are of great significance, for they appear to arise from a common causal factor or factors that influence the pink salmon population as a unit.

One biological explanation of the size variations from year to year is based on population density and the resulting competition among the individual salmon for food in the ocean as their numbers increase or decrease (Davidson and Vaughan, 1941).

Recent data (Skud, unpublished) from the

salmon fisheries of Southeastern Alaska indicate that pink salmon growth is independent of population density; similarly, Neave (1953) states that there is no evidence of an inverse association between growth and abundance in the British Columbia fishery. The mechanisms involved in the size fluctuations from year to year remain obscure, but the relative importance of population density cannot be ignored and perhaps should be considered on both an inter- and intra-specific basis.

Relation of Fish Size to the Timing of the Run

Davidson and Vaughan (1941) show that a significant correlation exists between size of pink salmon and times of the spawning migrations. The data were gathered from the pink salmon catch of the Clarence Strait fishery and the times of migrations were determined from catches of traps operated in this area. In the years salmon entered the fishery early in the season, the population was composed of large fish and in the years of later migration, the salmon were smaller.

There is evidence that this same relationship holds when fish ascend their home streams to spawn. Data gathered at Snake Creek, Etolin Island, (Fig. 2) are from Davidson and Vaughan (1941). The runs were earlier in years in which the average length of fish was greater.

Additional data on the size of the spawning adults were collected for most years of operation at Sashin Creek, Little Port Walter. The measurements were not standardized; body length (excluding head and tail) was measured from 1934–38 and during 1942, and fork length was used after that date. A conversion factor, 0.773, was determined to convert fork length to body length. The size of adult fish and time of arrival at Sashin Creek are compared in Figure 3. Owing to secondary sexual characteristics, female measurements are used because they are less variable than those of the male. Two points on the figure are questionable. The arrival date for 1937 is doubtful due to a severe flood that washed out the weir during the second week of September. That is, the date that 50 percent of the run was completed would be later than August 25, as shown on the graph. Field notes did suggest, however, that the majority of the run was completed prior to the flood and the resultant error is not considered significant. The high average length of fish in 1953 is based on measure-

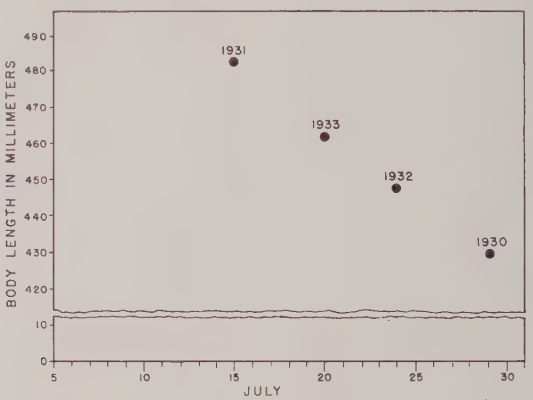

Fig. 2. Comparison of average length of adult females and date that 50 percent of the run passed through the counting weir at Snake Creek, 1930–1933.

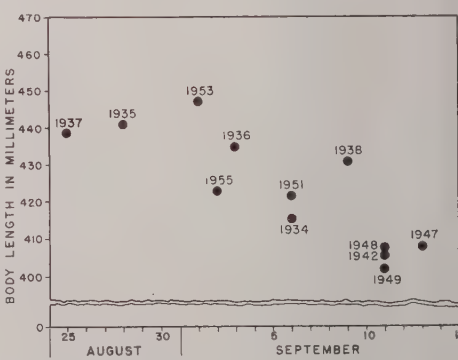

Fig. 3. Mean length of female pink salmon and date that 50 percent of the run passed through the counting weir at Sashin Creek.

ents of only 23 females, which is not considered to be an adequate sample. Nonetheless, two facts suggest that the distortion may not be too great. First, the sampling method used in 1953 provided for an unbiased selection of the fish to be measured. The sample included every tenth female that passed through the weir during a given period. Secondly, the statistics from various fishing districts show that the number of fish per case of canned salmon was significantly lower in 1953 than the average and indicates that the fish were exceptionally large[1]. This evidence suggests that the relative position of the 1953 point in Figure 3 can be accepted. These data show that early runs are associated with larger fish (correlation coefficient $= -0.84$, $p < 0.01$).

Because time of arrival at the weir does not necessarily indicate time of spawning and since no consecutive data are available on spawning time, the date that 50 percent of the run passed through the weir was selected as the time which was most representative of the peak of spawning. This does not imply that the 50 percent date of passage through the weir is coincident with the peak of spawning, but rather assumes that the peak of spawning will fluctuate from year to year in a manner not unlike that of the 50 percent arrival time. The conditions at Sashin Creek, Little Port Walter, are such that upstream movement of salmon is rarely, if ever, impeded by physical factors. At this station, Davidson et al (1943) tested, by means of correlation and path coefficient analyses, the interrelationship between various environmental conditions and their influence upon the upstream movement of salmon. Results of this work showed that rainfall or stream level may affect the movement upstream, but unless the salmon were sexually mature and ready to enter the stream they did not react to changes in its water level. These findings and unpublished field notes from Sashin Creek support the assumption that arrival time and spawning time fluctuate in a similar manner.

With the size-time relationship established between years, the same phenomenon within a year or run can be examined. In 1936 F. A. Davidson and S. J. Hutchinson (unpublished) sampled catches in two commerical traps in Southeastern Alaska. Trap-caught fish show no marked change in body structure owing to sexual development and both male and female measurements were included in this comparison. Davidson and Vaughan (1941) showed that the mean length of males was approximately 40 mm. greater than that of females. The number of males and females in the trap samples was not available. As shown later, the means of these samples were not significantly different. This fact indicated that the variation of sex proportions in successive samples was not extreme and possible distortion from this source was considered minimal. Samples of 25 fish each were measured every few days for a month. In combined samples of 100 fish, the mean body length at the Cape Chacon trap between July 18 and 26 was 434.40 mm.; between July 28 and August 7, 431.03 mm.; and between August 13 and 23, 429.84 mm. The standard error of these means was 3.01, 2.36 and 1.68 respectively. The means were not significantly different. The original measurements from the Dall Head trap were not available but the mean length for combined samples of 100 fish for the same 10-day periods were 439.69 mm. in the first, 436.14 mm. in the second, and 430.03 mm. in the third. Assuming that the probability of each possible combination of large, medium and small sample means is equal and that the two experiments are independent, the probability of obtaining the observed distribution in both the Cape Chacon and Dall Head samples in 2.8 percent.

The data available for examination of the size-time relationship within a run at Sashin Creek is limited. Length samples of adults were taken sporadically during given runs. As in the between years comparison at this stream, male measurements were not used because they are more variable than those of the female. Samples were limited to less than 50 fish each and were usually taken at 2-week intervals. The mean difference between early and late samples was 6 mm. In some cases, the differences were not greater than those expected by random sampling errors. However, in 8 out of 9 years the mean length of earlier fish was greater than that of fish arriving later in the run. Assuming that both large and small fish had an equal chance of appearing early in the run, the probability of obtaining the observed distribution is 1.7 percent.

The low probable occurrence of the ob-

[1] The number of fish per case in the years used in Figure 3.

Year	*Juneau District*	*Ketchikan District*
1953	16	14
1951	18	16
1949	23	20
1948	23	19
1947	23	19

served sequence of means in both the trap and stream data indicated that the distribution of fish size with time was influenced by a causal agent or agents other than chance. The biological significance of such small differences in length may be questioned, but this evidence from within a run does lend support to the size-time phenomenon as it occurs between years.[2] Hoar (1951) also reported that larger (by weight) fish entered the British Columbia fishery earlier within a season. He suggested that there was a relationship between rate of growth, onset of sexual maturity, and availability to the fishery.

Annual mean lengths of the Sashin Creek data were undoubtedly affected by the seasonal change of length within a run. The possible distortion was considered minimal for two reasons. First, annual means were determined from samples taken at varying intervals during the run. And secondly, the mean difference of annual length measurements were much greater than mean differences of samples taken during the run.

Thus these data indicate that: 1) adult migrations which occur earlier in one year than another are usually composed of larger fish, and 2) the females arriving early in a run are usually larger than late arrivals within the same run.

Relation of Timing to Survival of the Progeny in Freshwater

Freshwater survival of pink salmon at Sashin Creek is measured by the operation of a two-way weir, adults being counted as they ascend to spawn and the young as they migrate to sea (Table I). Female pink salmon average approximately 2,000 eggs per individual and survival has been calculated by dividing the actual downstream fry count by the potential egg number using the above average.[3]

The correlation coefficient between the time that 50 percent of the adult migration was completed and the rates of survival provides a highly significant value of -0.87, $P < 0.01$. The comparison does not include the 1950, 1952 and 1954 data because of the small numbers of spawners. The cor relation indicates that early time of arriva at the weir is associated with higher fresh water survival. A direct comparison may b made by a simple average survival from 1. The four earliest dates of arrival; 2. Th five "middle" dates; and 3. The four lates dates of arrival. These are respectively 8.8 2.1 and 1.0 percent. It may be concluded that the factors associated with early arriva result in better survival. Of these factor the early period of incubation may wel be the most important. This time-surviva relationship found at Sashin Creek may b applicable to other September runs. How ever, the differences of environmental con ditions could conceivably reverse or pre clude a similar relationship in July runs.

If, as the correlation suggests, years o early migration provide better survival than years of late migration, similarly, early ar rivals in a run may provide better survival than late arrivals of the same run and the first portion of a run may be of greater im portance to the escapement than the late portion.

The question may be raised, that if earl migrations provide better survival, why ther have not the runs increased in number and become progressively earlier? One hindranc to the runs becoming progressively earlie is the size fluctuation, for if oceanic con ditions do not promote growth to large size adults will not return as early as thei progenitors. Secondly, the changes in en vironmental conditions experienced by th eggs and fry during freshwater existenc can readily prevent increasing runs if ad verse conditions exist for one or more years

The Effect of Climatological Factors During the Incubation Period

The relationship of climatological factor to the freshwater survival of pink salmon warrants attention. Rainfall is measured a Little Port Walter is accordance with meth ods of the U.S. Weather Bureau. Tempera tures have been measured by seven-day ther mographs, including temperature of the air surface water and water 6-inches within th gravel of the spawning bed (depth of averag pink salmon nest). For a detailed discussion of the effects of climatological factors on survival, the reader is referred to papers b Pritchard (1948) and Neave (1953).

In some years freshwater survival rates a Little Port Walter were either at a lowe

[2] Attention is called to the fact that the relation of size to time is also in evidence during the seaward migration of the fry. Skud (1955) has shown that, at a given length, the weight of March migrants is greater than April migrants and April migrants greater than fry migrating in May.

[3] This involves a small error because the fecundity changes with the size of the female. The maximum error on an average, however, is only 10 percent and is not of a magnitude which would account for the large observed differences in survival rates.

or higher rate than might have been expected from the relation of percentage survival to time of the run; it is possible that these anomalies were caused by climatic conditions. For example, in 1943 when 50 percent of the migration had been completed by September 10, percentage survival was 1.5, a figure which is bettered in three years which have similar dates of arrival. During the incubation and post-hatching period of the 1943 brood several floods occurred which had catastrophic results on eggs and fry still in the gravel of the spawning beds. Thousands of eyed eggs and fry were found stranded on the stream bank following the scouring effects of the floods. This damage exceeded any observed subsequently or previously and could well account for the low rate of survival. As a second example, the incubation period of 1947–48 resulted in a fairly high survival rate, yet the time of arrival was late and supposedly would tend to provide a poor survival. This incubation period was one of the mildest on record, temperatures seldom dropping below freezing. These optimal temperatures, undoubtedly, resulted in fewer casualties than would normally be expected during the winter.

Discussion

The purpose of this paper has been to show that there is a relationship between the adult size of pink salmon and the time of migration to their home stream, Sashin Creek. The possible importance of arrival time to survival in freshwater is discussed. The element of timing and its relation to salmon runs is not new. Davidson and Vaughan (1941) stress the time factor in the commerical fishery and Pritchard (1937) and Davidson et al (1943) consider the timing of runs to their home streams.

The high coeffiicient of correlation between arrival time and survival does not preclude the effect of other factors. The importance of other elements and their influence upon survival merit attention. Per-

Table I

Annual Counts, Arrival Dates and Percentage Survivals of Pink Salmon in Sashin Creek, Little Port Walter, Alaska

Year	Date 50% spawners in the stream	Number of adult females	Potential number of eggs	Number of fry migrating seaward following spring	Percent freshwater survival
1934	Sept. 6	3,401	6,802,000	—	—
1935	Aug. 28	3,036	6,072,000	—	—
1936	Sept. 3	2,582	5,164,000	—	—
1937	Aug. 25	3,543	7,086,000	—	—
1938	Sept. 9	3,234	6,468,000	—	—
1939	Sept. 4	8,415	16,830,000	—	—
1940	Sept. 3	26,429	52,858,000	3,402,830	6.4
1941	Sept. 15	44,339	88,678,000	1,024,364	1.2
1942	Sept. 11	40,751	81,502,000	674,672	0.8
1943	Sept. 10	7,490	14,980,000	227,673	1.5
1944	Sept. 9	1,952	3,904,000	104,113	2.7
1945	Sept. 12	2,531	5,062,000	41,900	0.8
1946	Sept. 14	368	736,000	966	0.1
1947	Sept. 13	667	1,334,000	26,454	2.0
1948	Sept. 11	256	512,000	9,016	1.8
1949	Sept. 11	2,400	4,800,000	176,025	3.7
1950*	—	43	—	—	—
1951	Sept. 6	2,031	4,062,000	379,585	9.3
1952*	—	20	—	—	—
1953	Sept. 1	665	1,330,000	94,531	7.1
1954*	—	—	—	—	—
1955	Sept. 2	5,169	10,338,000	1,266,178	12.2

* Data from these years not used in comparisons made in the text, since the number of spawners was not considered sufficient for the analysis.

haps the most significant factor not taken into account in the present work is predation. The investigations of Ricker (1953) and Neave (1953) point to the importance of predators on survival.

Conclusions

The conclusions of this report are:

1. Yearly fluctuations in the average size of pink salmon appear to be uniform throughout the Southeastern Alaska fishery which suggests that these fish are affected as a unit by environmental factors met during their ocean existence.

2. During years in which the fish are large the runs tend to appear earlier than in years in which the runs consist of smaller fish.

3. Within a season, fish arriving earlier are larger than individuals arriving later in the same run.

4. At Sashin Creek statistical evidence suggests that years of early runs may provide for better survival of young during the freshwater incubation than years of late runs.

Literature Cited

Davidson, F. A., and Elizabeth Vaughan. 1941. Relation of population size to marine growth and time of spawning migration in the pink salmon (*Oncorhynchus gorbuscha*) of Southeastern Alaska. *Jour. Mar. Res., 2(3): 231–46.*

Davidson, F. A., Elizabeth Vaughan, S. J. Hutchinson, and A. L. Pritchard. 1943. Factors influencing the upstream migration of the pink salmon (*Oncorhynchus gorbuscha*). *Ecology, 24(2): 149–68.*

Hoar, William S. 1951. The chum and pink salmon fisheries of British Columbia, 1917–1947. *Bull. Fish. Res. Bd. Canada, (90): 46* pp.

Neave, Ferris. 1953. Principles affecting the size of pink and chum salmon populations in British Columbia. *Jour. Fish. Res. Bd. Canada, 9(9): 450–91.*

Pritchard, A. L. 1937. Variation in the time of run, sex proportions, size and egg content of adult pink salmon (*Oncorhynchus gorbuscha*) at McClinton Creek, Masset Inlet, B. C. *Jour. Biol. Bd. Canada, 3(5): 403–16.*

———. 1948. Efficiency of natural propagation of the pink salmon (*Oncorhynchus gorbuscha*) in McClinton Creek, Masset Inlet, B. C. *Jour. Fish. Res. Bd. Canada, 7(5): 224–36.*

Ricker, W. E. 1953. Numerical relations between abundance of predators and survival of prey. *Canadian Fish Cult., (13): 5–9.*

Skud, Bernard Einar. 1955. Length-weight relationship in migrating fry of pink salmon at Sashin Creek, Little Port Walter, Alaska. *Copeia, (3): 204–07.*

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Boothbay Harbor, Maine.

FILTERING EFFICIENCY OF HARD CLAMS IN MIXED SUSPENSIONS OF RADIOACTIVE PHYTOPLANKTON

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Abstract

Simultaneous removal of two species of phytoplankton by Mercenaria (= Venus) mercenaria L. was measured by labeling one species with P^{32} and the other with Ca^{45}. Since both species are removed from the same volume of water pumped, a faster removal of one indicates a greater efficiency of the clam in filtering that species. A species of Carteria was always one of two species in suspension, since it alone of 15 species tested had sufficient uptake and retention of Ca^{45} for use in these experiments. In general, algal cells 4μ or larger in diameter were filtered with uniform efficiency. Cells 2 to 3μ usually were not filtered as efficiently as larger cells in the same suspension, even though clams secreted much mucus, probably in an effort to retain these smaller cells. A dinoflagellate, Gymnodinium sp., caused most clams to close soon after filtering activities began. When clams remained open, they efficiently filtered Gymnodinium from suspension, but ejected chains of compact cells, which were 94% Gymnodinium, through their incurrent siphons. The population density, varying from 2 to 20 million cells per liter in most suspensions, did not affect the efficiency with which the species were removed.

Although extensive studies of the feeding behavior of filter-feeding lamellibranchs have been made, there remain some basic problems relative to filtering efficiency and factors affecting it. Variations in filtering rates of the hard clam, Mercenaria (= Venus) mercenaria L., result from a change in efficiency of particle removal or in volume of water pumped. In recent investigations Rice and Smith (in press) found that filtering rates of hard clams varied with different species of phytoplankton. Since these filtering rates were based on radiological measurements of P^{32} incorporated into the cells of only one species, it was not possible to determine whether these variations involved filtering efficiency of gills or volume of water pumped. A comparison of the simultaneous removal of two species from the same suspension would eliminate changes in rate of water propulsion as a

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factor. With both species in the same water, a faster removal of one would indicate greater efficiency in filtering that species. Removal of two species of algae from the same suspension can readily be followed when each species is labeled with a different radioisotope. The purpose of this investigation was to study the filtering efficiency of hard clams for different species of phytoplankton.

The radiosotopes employed for labeling algae were P^{32} and Ca^{45}. Their radioactive characterisitics differ sufficiently to allow separate determination of each isotope when both are present in a mixture. Calcium, like phosphorus, is essential in metabolism of algae. Only a small per cent of the calcium which occurs naturally in sea water is necessary for algal growth. Since the uptake of Ca^{45} is the same as that for non-active calcium, the dilution which occurs when this radioisotope is added to natural sea water prevents much Ca^{45} from being taken up by the algae. To increase uptake of Ca^{45}, artificial sea water was prepared without the addition of calcium (Rice 1956). Fifteen species of algae were tested for rate of cell division and uptake of Ca^{45} when grown in this artificial sea water containing Ca^{45}. In all experiments Carteria sp. was labeled with Ca^{45}, since it was the only species that had sufficient uptake and retention for use in these experiments. In suspension with Carteria, other species were labeled with P^{32} following the methods of Rice (1953) for obtaining highly radioactive cells.

The phytoplankton used may be grouped according to their length as follows:

Algae	Classification	Size (m)
Chromulina pleiades	Chrysophyceae	2
Nannochloris atomus	Chlorophyceae	3
Chlamydomonas sp.	Chlorophyceae	8
Gymnodinium sp.	Dinophyceae	9x12
Platymonas sp.	Chlorophyceae	9x14
Carteria sp.	Chlorophyceae	10x14
Amphydinium klebsi	Dinophyceae	12x17
Nitzschia sp.	Bacillariophyceae	4x17
Nitzschia closterium	Bacillariophyceae	5x38

The twelve clams used in this study were collected in the vicinity of the Fishery Radiobiological Laboratory, Beaufort, North

Table 1. Comparison of rates of filtration by the clam, Mercenaria mercenaria, of different species of algae with that of Carteria sp. when both species were present in the same suspension. (Half hour observations during an experimental time of 3 hours.)

Species mixed with Carteria sp.	Number of Experiments			
	Total	Both species removed at same rate[1]	Carteria sp. removed faster	Carteria sp. removed slower
Nitzschia closterium	37	32	3	2
Nitzschia sp.	12	12	0	0
Amphidinium klebsi	10	10	0	0
Chlamydomonas sp.	13	12	1	0
Platymonas sp.	8	8	0	0
Nannochloris atomus	17	6	11	0
Chromulina pleiades	17	8	9	0
Gymnodinium sp.	13	9	1	3

[1]Variance of less than 10 per cent between species

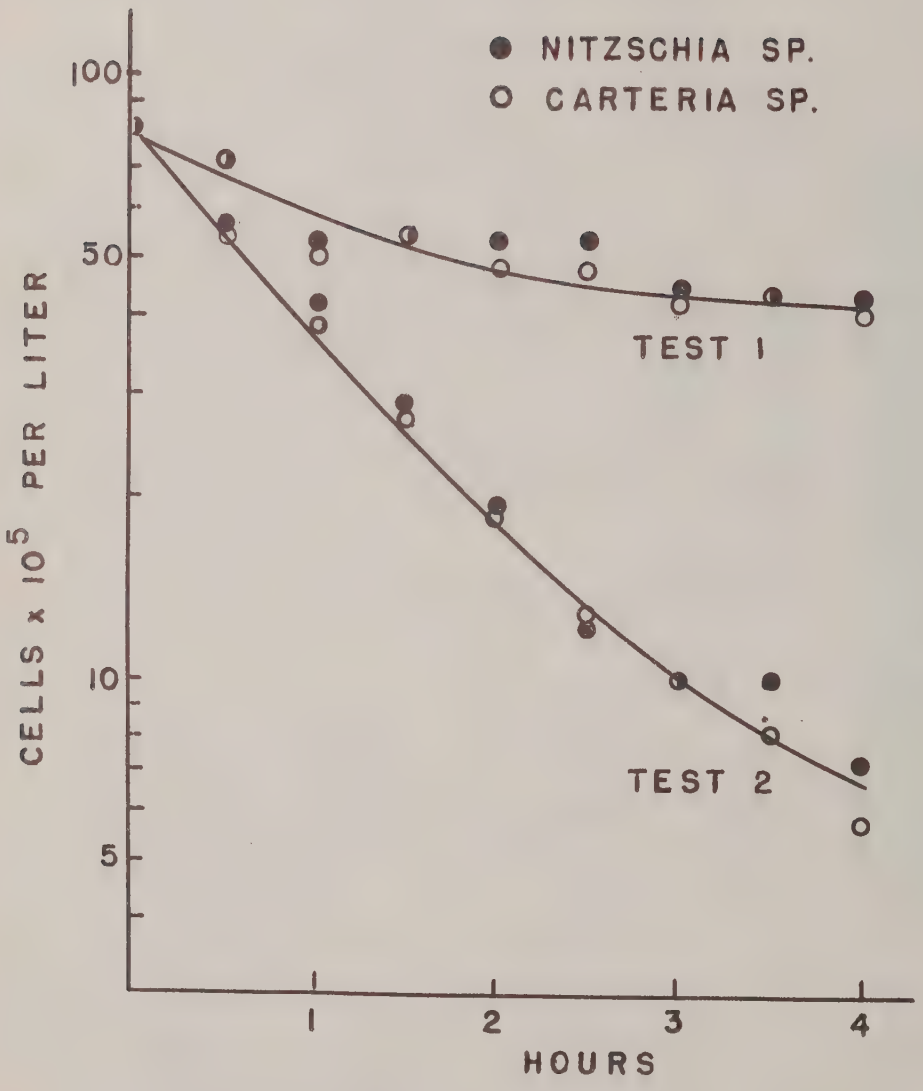

Fig. 1. Similarity of filtering efficiency of clams for two species of planktonic algae present in the same suspension in two tests in which the rate of filtration was different.

Carolina and were kept in running sea water when not being used in experiments. They ranged from 80 to 88 mm in length and from 66 to 77 mm in height. Each of three clams was placed in ten liters of filtered sea water to which had been added measured numbers of Carteria cells containing Ca^{45} and cells of a second species of algae labeled with P^{32}. The suspensions were adequately stirred to prevent any settling of cells. In control jars containing no clams, the numbers of cells in suspension at the beginning and the end of experiments were the same. When clams were placed in suspensions of some algal species, considerable numbers of cells quickly adhered to shell surfaces. Further tests showed that coating the shells with thin layers of paraffin prevented significant losses of cells from suspension.

Samples were taken of the suspension before adding a clam and at 30-minute intervals for 3 hours after it had opened. After filtration of cells from samples with millipore filters, measurements of their radioactivity due to Ca^{45} and P^{32} were made. Rates of removal of both algal species in suspension were calculated from these measurements.

It is believed that the decrease in cell numbers in suspension represents filtration by the clam, although it is not definitely known whether filtered cells which may be rejected are sufficiently free of mucus to go back into suspension. There is reason to believe, however, that rejected cells are bound in mucus and do not break up and re-enter the suspension.

With the exception of tests using Nannochloris atomus, Chromulina pleiades and Gymnodinium sp., the decrease in cell numbers of any species during any half hour of a 3-hour observation period never varied over 10 per cent, and usually not over 5 per cent, from that of Carteria. In only 6 out of 80 experiments was the rate of removal of one species different from that of the other (Table 1). Even in these instances the difference in filtering efficiency was only significant during the first hour of filtering activity.

Whether cells of these algal species were completely filtered from the water pumped was not determined. When algae of different sizes such as Nitzschia and Carteria were filtered with the same efficiency, it is believed that all cells were removed from water passing through the gills. It is improbable that algae of such unlike size and shape could escape the gills at the same rate. If the species in suspension are similar in size, a uniform percentage of escapement is possible.

The rate of filtration apparently did not affect the efficiency with which clams removed either species. Figure 1 shows results of two representative experiments. During the observational time the clam in Test 1 removed cells of Nitzschia sp. and Carteria sp. as efficiently as the clam in Test 2, yet filtered them at a much slower rate, due to less water being pumped through its gills. Figure 4

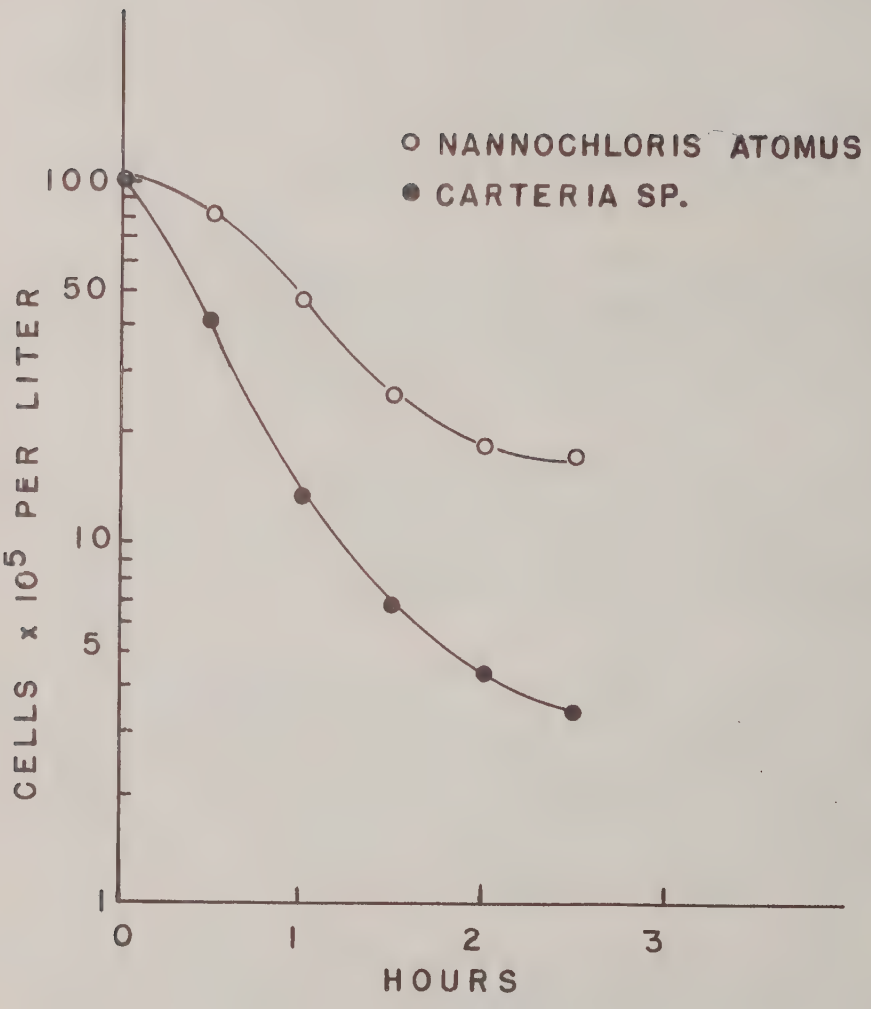

Fig. 2. Differences in filtering efficiency of clams for two species of planktonic algae in the same suspension.

shows that all three clams removed both algal species with the same relative efficiency during the 3 hour period, yet filtered the cells at a faster rate during the first 1 1/2 hours. When both species were removed at a faster rate during one time interval than another, this indicated a change in volume of water pumped, since the filtering efficiency for each species had not changed.

In 20 of 34 experiments when Chromulina pleiades or Nannochloris atomus were in suspensions with Carteria, the clams removed Carteria at a faster rate than either of the other species (Table 1). Figure 2 shows the results of one of these experiments in which many small cells escaped the gills. A more abundant formation of mucus was observed in tests containing N. atomus and C. pleiades, but this was ineffectual in preventing considerable escapement of cells.

In 14 of 34 experiments the percentage decrease in cell numbers of N. atomus and C. pleiades during each hour did not differ more than 10 per cent from that of Carteria cells. Rice and Smith (in press) have shown that filtering rates of hard clams in certain unialgal suspensions were altered considerably when other algae were added. A more efficient retention of N. atomus was observed when Nitzschia closterium was present; this may have resulted from a clogging of gills by the large cells of Nitzschia. In other experiments yet unpublished, the percentage escapement of N. atomus through the gills of oysters averaged 88 per cent; this was reduced to 51 per cent by addition of Carteria to the suspension. It seems possible, therefore, that the presence of relatively large Carteria cells increased the efficiency of retention of small cells of N. atomus and C. pleiades by the hard clam.

In 9 of 13 experiments Gymnodinium and Carteria were removed with similar efficiency (Curve B in Figure 3). In the other 4 tests the presence of Gymnodinium resulted in variations in rates of removal of Carteria. Curve A shows these fluctuations in the filtering rate of Carteria, but a steady rate of removal of Gymnodinium.

Apparently the use of different cell densities of each species did not change the efficiency of removal. The total number of cells in each suspension was kept low, never exceeding 20,000,000 cells per liter, except in 6 tests containing 73,000,000 Nitzschia closterium cells per liter and 26,000,000 Carteria cells per liter. Previous experiments (Rice and Smith, in press) have shown that dense suspensions stimulate secretion of mucus with a resultant increase in production of pseudofeces. A comparison of the results of tests using suspensions of different population densities (Figure 4) shows that cells of Nitzschia closterium and Carteria sp. are removed with similar efficiency at the various time intervals.

The presence of Gymnodinium sp. seemed to have a definite effect on the feeding behavior of clams. In many tests it was impossible to obtain data since the clams closed soon after filtering

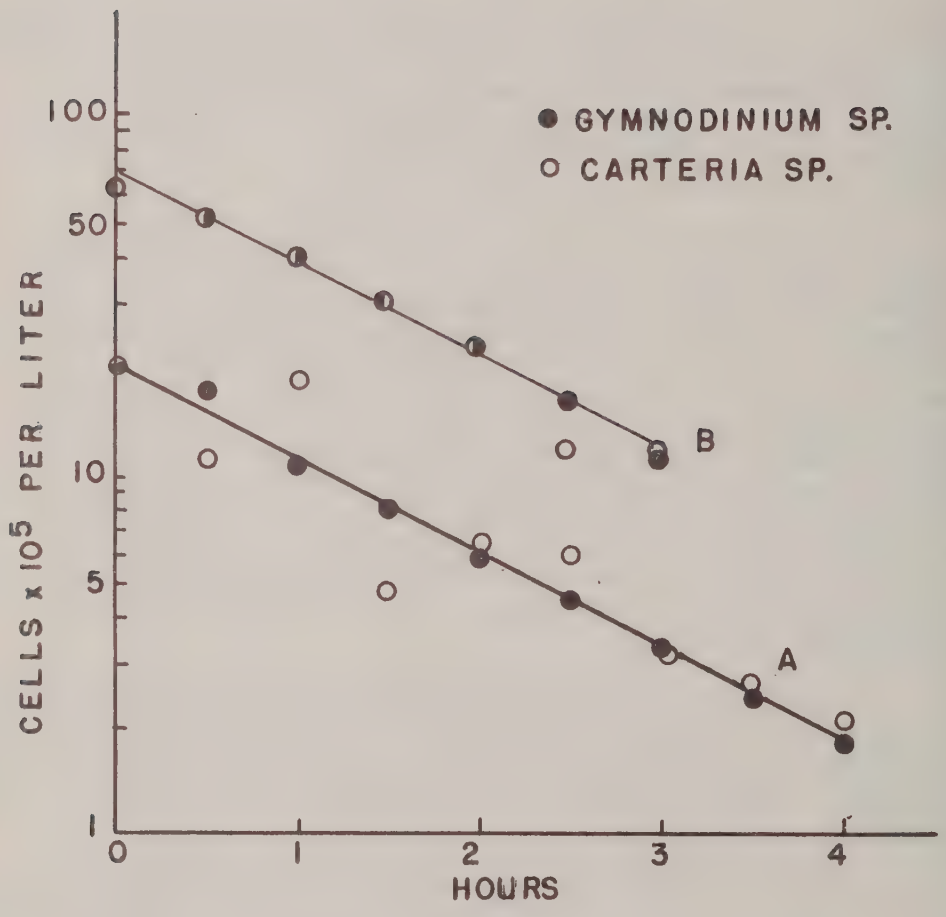

Fig. 3. In nine experiments Gymnodinium and Carteria in mixed suspensions were removed with similar efficiency (Curve B) but in the remaining four experiments the presence of Gymnodinium affected the rate of filtering of Carteria (Curve A).

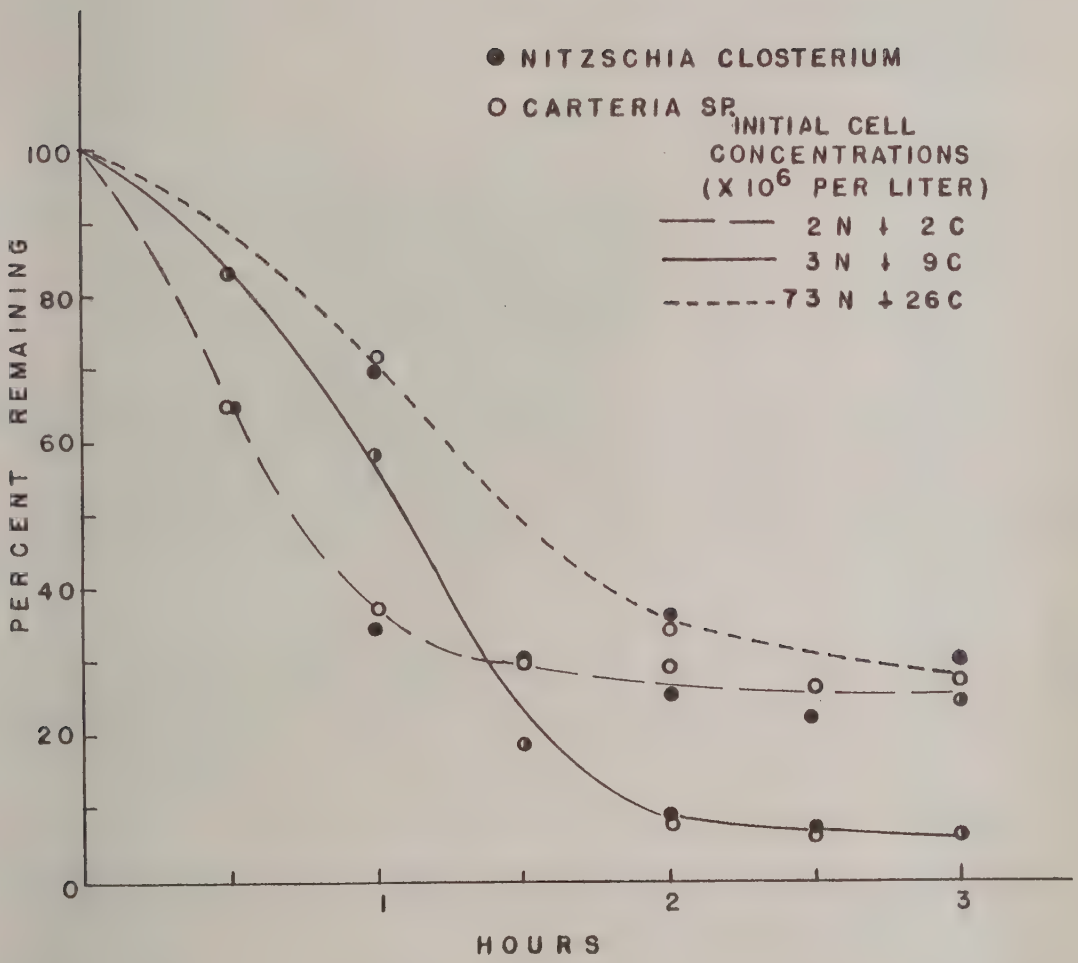

Fig. 4. Effects of densities of two species of planktonic algae in mixed suspensions on efficiency of removal by clams.

activities began. When they did remain open, chains of compact cells were ejected through the incurrent siphons. Some of these rejected cells were collected, washed several times in sea water and dissolved in acid so that thin samples could be prepared to minimize self absorption of beta particles of Ca^{45}. These samples were measured for their P^{32} and Ca^{45} content. Ninety-four per cent of the cells in these chains were Gymnodium, which demonstrated that the clams were selectively rejecting this dinoflagellate after filtering it from the water. This ejection of chains of cells was frequently observed only in tests using Gymnodinium.

Identification of the species of Gymnodinium used in this investigation needs to be made, since different results have been obtained with other species of this dinoflagellate. Ballatine and Morton (1956) found that Gymnodinium veneficum caused the small clam, Lasaea rubra, to cease filtering and to close its shell. It is known that Gymnodinium brevis produces a substance that is highly toxic to marine animals. Gymnodinium splendens, however, has been reported to be an excellent food organism for oysters.

The results of these studies demonstrate that the hard clam, Mercenaria mercenaria, does not filter algal cells of different sizes with the same efficiency. Cells of 2 to 3μ are not removed as efficiently as those of larger size in the same suspension, even though these larger cells aid in retention by gills. In general, cells which are 4μ or larger in diameter are filtered with uniform efficiency.

Thanks is given to Dr. W. A. Chipman and Dr. T. R. Rice of this laboratory. Dr. Chipman offered helpful suggestions and assisted in evaluating and reporting results. Dr. Rice advised in investigational procedures and made available unialgal cultures of phytoplankton.

Literature Cited

Ballantine, Dorothy and J. E. Morton. 1956. Filtering, feeding, and digestion in the lamellibranch Lasaea rubra. Jour. Mar. Biol. Assoc. U.K., 35: 241-272.

Rice, Theodore R. 1953. Phosphorus exchange in marine phytoplankton. Fishery Bull. U. S. Fish and Wildlife Serv., 54 (80): 77-89.

Rice, T. R. 1956. The accumulation and exchange of strontium by marine planktonic algae. Limnol. & Oceanogr. 1: 123-138.

Rice, T. R. and Rebecca J. Smith. Rates of filtration by Venus mercenaria (L.) determined with radioactive phytoplankton. Fishery Bull. U. S. Fish and Wildlife Serv., 58 (129): (in press).

NOTES ON A TOXIN FROM *GYMNODINIUM BREVE*

By

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NOTES ON A TOXIN FROM *GYMNODINIUM BREVE*

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Catastrophic fish mortalities associated with algal blooms have occurred at various times throughout the world (Connell and Cross, 1950; Ballantine and Abbott, 1957). In the Gulf of Mexico, blooms of *Gymnodinium breve* (Davis, 1948) accompanied massive fish kills which were reported along the west coast of Florida (Gunter *et al.*, 1948), the southeast coast of Texas, and the northeast coast of Mexico (Wilson and Ray, 1956). *G. breve* appears to be widely but sparsely distributed in the Gulf of Mexico. A critical combination of chemical and physical factors sets off blooms (Ketchum and Keen, 1948; Gunter *et al.*, 1948; Hela, 1955; Chew, 1955).

Until recently, studies of the metabolism, physiology, and toxin of *G. breve* were hampered because of the fragile nature and fastidious growth requirements of this organism. Wilson and Collier (1955) developed an enriched sea-water medium which supported growth and serial transfer of unialgal cultures of *G. breve*. Their mass cultures killed fish. Ray and Wilson (1957) then isolated *G. breve* and showed that pure cultures killed fish. They reconfirmed the toxicity of unialgal cultures.

This study describes some procedures for the bioassay of the toxin in unialgal cultures of *G. breve* and some properties of crude toxin preparations.

Materials and Methods

Growth of mass cultures. Unialgal mass cultures of *G. breve* were grown in 20 liter carboys containing 15 liters of the sea-water medium described by Wilson and Collier (1955) with (a) half the amount of soil extract, (b) 3 x the final concentration of $Na_2S \cdot 9H_2O$, and (c) omission of EDTA. Good growth (1 to 3 million living cells per liter) was obtained in 4 to 8 weeks; toxicity experiments were then conducted.

Bioassay organisms. In early experiments the guppy, *Lebistes reticulatus*, was used to compare the potencies of different preparations of *G. breve*. The guppies, bred in quantity in laboratory tanks, were available throughout the year. Although the guppies did not breed in waters of high salinity (approximately 2.8 to 3.3 per cent) they survived at these salinities and could be transferred from fresh water without adverse effects. This ability to withstand high

salinities was a prerequisite for its use in bioassays since most of the tests were made in the sea-water medium (salinity, 2.8 to 3.3 per cent, pH 7.9 to 8.2) described above.

In later experiments mullet, *Mugel cephalus*, were used. Small mullet (approximately 2.8 to 3.0 cm.) were readily available in the immediate vicinity of December through June. As they could not be maintained under our laboratory conditions for more than a week without loss of vitality, they were caught with a dip net when needed (several hundred at a time from one school) and used within 1 to 3 days. Small mullet proved sensitive to changes in salinity. Those caught in low-salinity waters (0.3 to 0.8 per cent) were gradually adjusted to higher salinities (2.8 to 3.3 per cent) by the dropwise addition of saturated NaCl to their holding tanks (100 liters) over a period of 24 to 36 hours. Usually this adjustment was unnecessary.

Responses of bioassay organisms to the toxin. Most of our toxin preparations from unialgal mass cultures (1.5 million cells per litter) killed mullet within 2 to 4 minutes. As the preparations were diluted, the symptoms of distress and time to death were prolonged. Mullet showed the following: within 30 seconds a violent twisting and turning accompanied by cork-screw type movements; then contractions and tail curvature at intervals of 10 to 20 seconds; within 1 to 2 minutes equilibrium is lost and fish may turn upside-down or on its side; opercular movements are irregular and slow; little response to probing and they may remain quiescent; immediately before death a violent burst of activity occurs and the fish dies with mouth and opercula opened. Once equilibrium is lost, removal to non-toxic water does not aid recovery.

Toxin preparations which kill mullet in 2 to 4 minutes kill guppies in 8 to 15 minutes. The response of the guppy is sluggish compared to the mullet but the symptoms are similar. It remains to be seen if the toxin acts alike in both fish.

These symptoms are remarkably similar to those described by Abbott and Ballantine (1957) for *Gobius flavescens* (goby) in a toxic preparation of *Gymnodinium veneficum* (Ballantine, 1956).

Bioassay techniques using mullet. One liter aliquots of a mass culture (final pH 8.15, salinity 3.3 per cent, 7 weeks old) having a living cell count of 1.5 million per liter were frozen overnight in flasks. The contents were thawed in a water bath at room temperature (25±2° C.) and filtered through an AA millipore filter. Dilutions were made from the cell-free preparation with sea-water medium (pH 7.9, salinity 3.3 per cent) to give the following final concentrations: (ml. *G. breve* preparation per 100 ml. final solution) 0.0, 2.5, 5.0, 10.0, 20.0, 30.0, 40.0, 50.0, 75.0 and 100.0. One hundred ml. of each dilution were put into 250 ml. beakers. Mullet were washed in the uninoculated sea-water medium for 15 to 30 minutes. At zero time, fish were added to each dilution and death times recorded.

Results

Preliminary experiments with guppies and mullet indicated that living cultures of *G. breve* were less toxic than killed ones.

In many instances, our test organisms remained active for approximately one hour in a culture of live *G. breve*. However, aliquots of the culture, previously treated to destroy *G. breve*, killed both assay organisms in a matter of minutes. Gentle heating, quick freezing, pH changes, vacuum filtration, changes in osmotic pressure, and addition of certain heavy metals to aliquots of the culture, all increased toxicity.

Standard bioassay death curve for mullet. The standard bioassay death curve (Fig. 1) was made with a cell-free preparation. It represents a composite of 4 experiments with a total of 12 to 16 fish for each dilution tested.

Minimum and maximum death times are indicated by the extremes of the vertical lines. The points at which the assay curve passes through the vertical lines are the average death times of mullet in the indicated concentration of the *G. breve* preparation. As shown, undiluted cell-free preparations (100 per cent) killed mullet within 2 to 4 minutes; with increasing

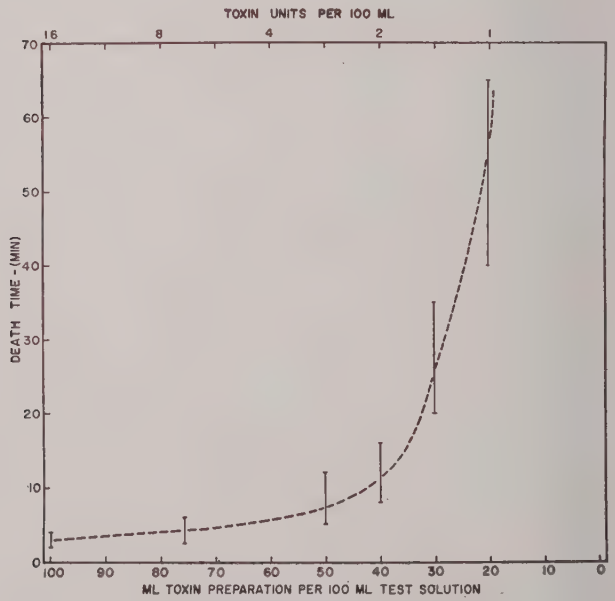

Fig. 1. Response of mullet to *Gymnodinium breve* toxin dilutions. Arbitrary toxin units (TU) defined in text.

dilutions, average death times were increased. In a 20 per cent dilution, mullet were killed in approximately 60 minutes. A 10 per cent dilution proved toxic in 4 to 8 hours and sometimes not at all. At concentrations below 10 per cent and in controls, mullet were still alive after 72 hours at which time the experiment was discontinued. Death times at specific concentrations increased with decreasing dilutions of the original preparation as indicated by the heights of the vertical lines in figure 1. Thus, at concentrations representing 100, 75, 50, 40, 30, and 20 per cent of the cell-free preparation, the death range for different mullet was 2, 4, 7, 8, 15, and 25 minutes, respectively. At concentrations representing 10 per cent of the original preparation which at times would kill mullet within 4 to 8 hours or not at all, the variability in death time was too great for inclusion in the standard curve.

Comparison of Abbott and Ballantine's (1957) data with ours suggests a similarity of action between the *G. veneficum* and *G. breve* toxins. They reported that a strong toxic culture of *G. veneficum* killed gobies in 5 to 6 minutes. Our usual cell-free preparations killed mullet within 2 to 4 minutes. Preparations diluted to 60 per cent killed within 5 to 6 minutes. Occasionally concentrated preparations were obtained which killed within 30 to 60 seconds.

The toxin unit. One *G. breve* toxin unit (TU) is defined arbitrarily as the amount of toxin per 100 ml. of sample which under standard conditions will kill *Mugel cephalus* in 60 ± 15 minutes and a two-fold dilution of which may kill within 4 to 8 hours or not at all. The standard conditions include: mullet 2.5 to 3.0 cm. in total length, 100 ml. of test solution contained in 250 ml. beakers, controlled temperature 25 ± 2° C., immediate use of test solutions (some activity is lost on standing for prolonged periods), and appropriate salinity and pH controls.

Effect of temperature on toxicity. In preliminary experiments, aliquots of living cultures of *G. breve* exposed to lethal temperatures below 10° C. or above 37° C. proved more toxic than the original culture. Freezing-thawing or a 1 to 3 minute exposure at 50° C. were most effective in this respect.

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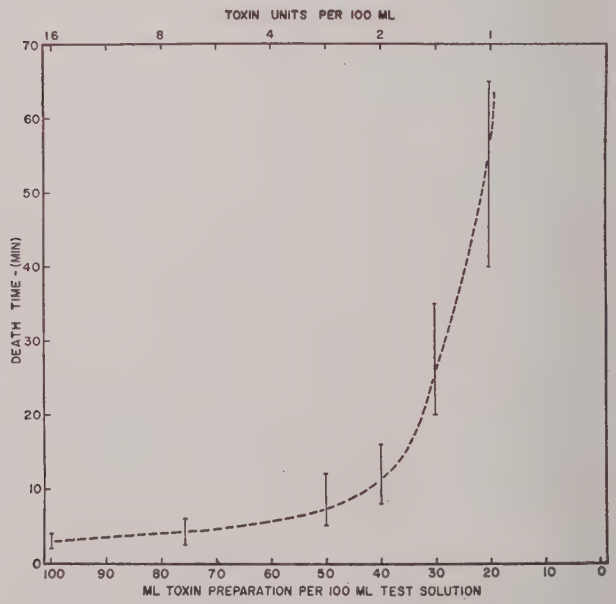

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Unialgal mass cultures of *G. breve* and uninoculated control medium were divided into liter aliquots and frozen overnight. After thawing in a water bath at 25° C., aliquots were assayed

and contained 16 TU (killed mullet in 2 to 4 minutes). Other aliquots were filtered through AA millipore filters. Residues (cell debris) were reconstituted with control medium to concentrations representing 20 x the original culture. Little or no activity was detected. The supernate or cell-free preparation contained most of the original activity (16 TU).

The effect of temperature on cell-free preparations containing 16 TU was tested in two series of experiments. In the first, a 2 liter aliquot was placed into a 4 liter flask and heated on a hot plate. Aliquots of 100 ml. were removed at temperatures of 25, 50, 65, 80, and 100° C., cooled immediately to 25° C. in an ice bath, and assayed. Little or no activity was lost from a cell-free preparation heated to 80° C. (Table 1). Approximately 1 TU

TABLE 1

Effect of increasing temperatures on the toxicity of cell-free preparations of Gymnodinium breve *with mullet the assay organism*

Temp. ° C.	Death Time Range (min.)
25	3–4
50	3–4
65	4–7
80	3–8
100	47–80

remained in aliquots of cultures heated to 100° C. In the second series, 2 liter aliquots of a cell-free preparation (16 TU) were placed in constant temperature baths at 25, 45, 55, and 100° C. After reaching the indicated temperatures, 100 ml. aliquots were removed at various times (Table 2), cooled to 25° C. in an ice bath, and assayed. Only 1 to 2 TU could be detected in those samples heated to 45° C. for about 4 hours or to 55° C. for 2 hours. No toxicity could be detected in samples held at 100° C. for 5 minutes.

Effect of pH on toxicity. The influence of pH on the toxicity of a living *G. breve* culture and on the toxicity of a cell-free preparation was tested. Aliquots of a culture (5 weeks old, final pH 8.1, salinity ca. 3.0 per cent, living cell count 1.2 million per liter) and uninoculated control medium were adjusted with 5 N HCl or 5 N NaOH to pH 3.3, 5.4, 7.0, 8.1, and 9.5 (precipitates occurred at the latter pH). At pH 3.3, 5.4, and 9.5, *G. breve* cells were destroyed and mullet were distressed in 17 to 19 minutes. At the original pH 8.1, *G. breve* remained active for an extended period

TABLE 2

Effect of exposure time at elevated temperatures on the toxicity of cell-free preparations of Gymnodinium breve *with mullet the assay organism*

Time (min.)	Average Death Time (min.) 25° C.	45° C.	55° C.	100° C.
0	3.5	3.5	3.5	64
5	..	..	3.5	still alive 72 hr.
15	..	..	4.0	still alive 72 hr.
25	..	3.5	..	still alive 72 hr.
30	3.5	..	15	.....
40	..	..	22	still alive 72 hr.
60	3.5	..	..	.....
65	..	3.5	..	.....
90	..	..	36	.....
120	4.5	..	..	.....
137	..	..	190	.....
150	..	42	..	.....
180	..	..	250	.....
240	4.0	..	...	.....
285	..	120	...	.....

and mullet were distressed in 45 minutes. All fish in pH control vessels appeared normal after 2 hours except for those held at pH 3.3 which showed signs of distress.

A similar test was made with a cell-free preparation containing 4 TU (killed mullet in 5 to 10 minutes). Aliquots were adjusted to pH 5, 6, 7, 8, and 9. The average death times for mullet in solutions at these pH levels were 5, 4, 8, 9, and 7 minutes, respectively. Other aliquots were adjusted to the same pH levels, readjusted to pH 8.0, and then tested. There was no apparent change in toxicity of the original preparation due to pH changes. Controls were still alive after 24 hours.

Within the range of values tested, pH does not modify the activity of the toxin as it affects mullet. However, a radical pH change which destroys *G. breve* enhances the toxicity of the original culture.

The effect of heavy metals on toxicity. The effect of heavy metals on the toxicity of a living culture of *G. breve* was tested. Salts of Sr, Zr, Hg, Ag, and Cu (final concentrations 5 ppm.) were added to 100 ml. aliquots of a culture. Distress times of the guppy and the state of activity of *G. breve* were recorded (Table 3). Hg, Ag, and Cu were lethal to *G. breve* within 7 minutes and guppies showed signs of distress within 13 to 18 minutes. Zr and Sr were less effective in this respect; *G. breve* remained active for ca. 60 minutes and guppies showed signs of distress within 111

TABLE 3

Effect of heavy metals on Gymnodinium breve *and on the toxicity of a living culture with guppy the assay organism*

Metal (5 ppm.)	State of *G. breve*	Average Distress Time for Guppy
Control, no addition	dying—100 min.	120 min.
Sr, as $SrCl_2 \cdot 6H_2O$	dying— 60 min.	183 min.
Zr, as $ZrOCl_2 \cdot 8H_2O$	dying— 60 min.	111 min.
Hg, as $HgCl_2$	dead — 7 min.	18 min.
Ag, as $AgNO_3$	dead — 7 min.	13 min.
Cu, as $CuSo_4 \cdot 5H_2O$	dead — 7 min.	13 min.

to 183 minutes. In controls containing no added metals, guppies were distressed in 120 minutes at which time the numbers of living *G. breve* had decreased considerably. These results indicated that metals which destroy *G. breve* effectively enhance the toxicity of the culture.

Attempts to concentrate the toxin. These experiments indicated that the toxin is confined mainly within the living organism. Attempts were then made to harvest intact cells for possible concentration and isolation of the toxin. Vacuum filtration and slow centrifugation were ineffective because the fragile *G. breve* was destroyed with release of the toxin. Intact cells were absorbed on filter paper but the activities of the reconstituted residues decreased with increasing volumes of the original culture. Thus, the filtrate of several liters of culture contained most of the original activity. However, the residue from smaller volumes (50 to 200 ml.) was absorbed on the filter and the toxin could be eluted from it with little loss of the original activity.

Charcoal and alpha cellulose at various acid and alkaline pH's destroyed or removed the toxin from living cultures and cell-free preparations. Attempts to elute the toxin with organic solvents and buffers failed. Aliquots of a living *G. breve* culture in cellulose dialyzing tubing were dialyzed against several changes of distilled water. Samples removed from the bag after 6 hours (*G. breve* was destroyed) contained most of the original activity.

Summary

Some properties of a toxin in unialgal mass cultures of *Gymnodinium breve* are described. Mullet and guppies were used to compare the potency of different toxin preparations. *G. breve* is extremely sensitive to chemical and physical manipulation

and the toxicity of a living culture is increased by agents which destroy *G. breve*. Such observations indicate that the toxin is largely within the cell. However, the fragility of *G. breve* has rendered fruitless attempts to concentrate intact cells as a means of concentrating the toxin.

In the absence of further information, it is difficult to compare the toxin of *Gymnodinium veneficum* (Abbott and Ballantine, 1957) with the toxin of *G. breve*. They are probably similar. Although the *G. veneficum* toxin has been described as an exotoxin (secreted into the water), it is difficult to tell whether *G. breve* produces a true exotoxin (freely secreted or excreted into the environment by living cells) or an endotoxin (liberated from the cells by lysis or autolysis).

REFERENCES AND NOTES

Abbott, B. C., and D. Ballantine: The toxin from *Gymnodinium veneficum* Ballantine. *J. Marine Biol. Assoc. United Kingdom*, 36: 169–189, 1957.

Ballantine, D.: Two new marine species of *Gymnodinium* isolated from the Plymouth area. *J. Marine Biol. Assoc. United Kingdom*, 35: 467–474, 1956.

Ballantine, D., and B. C. Abbott: Toxic marine flagellates; their occurrence and physiological effects on animals. *J. Gen. Microbiol.*, 16: 174–281, 1957.

Chew, F.: Red tide and the fluctuation of conservative concentrations at an estuary mouth. *Bull. Marine Sci. Gulf and Caribbean*, 5: 321–330, 1955.

Connell, C. H., and J. B. Cross: Mass mortality of fish associated with the protozoan *Gonyaulax* in the Gulf of Mexico. *Science*, 112: 359–363, 1950.

Davis, C. C.: *Gymnodinium brevis* sp. nov., a cause of discolored water and animal mortality in the Gulf of Mexico. *Bot. Gaz.*, 109: 358–360, 1948.

Gunter, G., R. H. Williams, C. C. Davis, and F. G. W. Smith: Castrophic mass mortality of marine animals and coincident phytoplankton bloom on the west coast of Florida, November 1946 to August 1947. *Ecol. Monogr.*, 18: 309–324, 1948.

Hela, I.: Ecological observations on a locally limited red tide bloom. *Bull. Marine Sci. Gulf and Caribbean*, 5: 269–291, 1955.

Ketchum, B. H., and J. Keen: Unusual phosphorus concentrations in the Florida Red Tide sea waters. *J. Marine Res.*, 7: 17–21, 1948.

Ray, S. M., and W. B. Wilson: Effects of unialgal and bacteria-free cultures on *Gymnodinium brevis* on fish. *Fishery Bull. No. 123*, 57: 469–495, 1957.

Wilson, W. B., and A. Collier: Preliminary notes on the culturing of *Gymnodinium brevis* Davis. *Science*, 121: 394–395, 1955.

Wilson, W. B., and S. M. Ray: The occurrence of *Gymnodinium brevis* in the western Gulf of Mexico. *Ecology*, 37: 388, 1956.

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SPECIFIC DETERMINATION IN THE TREMATODE GENUS, *GYMNOPHALLUS*

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Sexually mature specimens referable to the genus *Gymnophallus* occur in the gall-bladder, intestine, caeca and bursa Fabricii of shore-birds. Repeated observations have shown that the asexual generations of these worms occur in bivalve mollusks and that the cercariae, which are produced in sporocysts, belong to the Dichotoma Group of furcocercous larvae. Typically, these cercariae have eye-spots and short, bifid tails, although either or both may be reduced or absent. *Cercaria dichotoma*, discovered in plankton from the Mediterranean, emerges and swims as a furcocercous larva. In certain species the tail undergoes regression and is lost before the larva emerges from the sporocyst, whereas in others apparently no tail is formed. On emergence from the first intermediate host, the cercariae attach to the mantle or body-wall of bivalve or gastropod mollusks where, as unencysted metacercariae, they develop to almost definitive size. The metacercariae produce lesions on the mantles of their hosts and such injuries may stimulate proliferation of tissues, especially of the secreting layer of the mantle, with deposition of nacreous material. Despite the observations of many investigators over a period of more than fifty years, no complete life-history has yet been worked out and the specific relations between particular cercariae, metacercariae and sexually mature worms remain undetermined.

The presence of pearly formations in the mantle of *Mytilus edulis* has been known for at least three hundred years. According to Giard (1907) they were reported by Olaus Worm in 1665 from mussels taken at Roeskild, near Copenhagen. Robert Garner observed them in *M. edulis* from the English coast and he (1872) recognized that they were formed as a reaction by the mollusk to a small distome, parasitic on the mantle. Study of the trematodes which incite pearl-formation has been conducted by many investigators. Giard (1897) reported that the worms are juvenile, and he recorded them from *Donax truncatus* and three species of *Tellina* at Boulogne-sur-Mer. Dubois (1901) described the species from *M. edulis* at Billiers (Morbihan), France, as *Distomum margaritarum*.

Sporocyst and cercarial stages of these trematodes were reported from *Macoma balthica* by von Siebold (1837) and Markowski (1936); from *Scrobicula tenuis* by Villot (1875) and Lebour (1908); from *Tapes decussatus* by Jameson (1902); from *Cardium edule* by Huet (1889), Jameson (1902), Lebour (1904, 1905), Johnstone (1905), Nicoll (1906), Cole

(1938), Rees (1939), and Hutton (1952); from *Tellina solidula* by Pelseneer (1906); from *Syndosmya alba* by Pelseneer (1906) and Sinitsin (1911); from *Mya arenaria* by Stafford (1912) and Uzmann (1952); from *Mytilus edulus* by Cole (1935); and from *Hiatella artica* and *Hiatella striata* by Hutton (1953). Although all of these larvae appear to be developmental stages in species of *Gymnophallus*, specific determination is difficult and uncertain. In a series of papers, Lebour (1904, 1905, 1908, 1912) described gymnophallid larvae, but failed to distinguish between cercariae and metacercariae. Certain of the worms described by her as cercariae were actually metacercariae, but since the metacercariae are not encysted, distinctions are not precise and determinations may be equivocal. In addition to the metacercariae from *M. edulis* named by Dubois (1901), other species were reported from *Donax truncatus* and *Tellina* spp. by Giard (1897), Pelseneer (1906), Lebour 1908, and Rees (1939); from *Hiatella rugosa* by Odhner (1905); from *Paludestrina stagnalis* and *Macoma balthica* by Lebour (1908); from *Syndosmya alba* and other mollusks by Sinitsin (1911); from *Mytilus galloprovincialis* and *Tapes pullastra* by Dollfus (1923) and Palombi (1934); and from *Paphia* (*Ruditapes*) *philippinarum* by Ogata (1944).

Odhner (1900) designated *Distomum deliciosum* Olsson, 1893, from the gall-bladder of *Larus* spp. as type of a new genus, *Gymnophallus*. In the genus, he included *Distomum somateriae* Levinsen, 1881, *Distomum microphary*ngeum Lühe, 1898, and two new species, *G. choledochus* and *G. bursaria*. Seven additional species of the genus have since been described, but specific limits are indistinct and the validity of the named species is doubtful. Comparisons of cercariae, metacercariae and adult stages have often been made, but in the absence of experimental evidence it is impossible to identify any cercaria with the metacercaria or corresponding adult form. The situation is chaotic, but challenging. It would be of great interest to know whether or not members of a given species can develop in more than one location, viz. gall-bladder, intestine, caeca or bursa; and to know to what extent the influence of the host-species affects the development and morphology of the parasite.

Experimental analysis of the problem was begun by Jameson and Nicoll (1913) who reported that metacercariae from *M. edulis* did not develop in *Oidemia nigra* or *Fuligula* (*Nyroca*) *ferina*. In collaboration with J. R. Uzmann, I have attempted to infect various possible hosts with metacercariae from *M. edulis* of the New England coast. Our only success so far was with recently hatched chicks of *Somateria mollissima*, from which adult worms were recovered. However, such young birds have little resistance to infection and older eider ducks may be refractory. Metacercariae transferred from *M. arenaria* to *M. edulis* and to *H. arctica*, and others removed from *H. arctica* to *M. arenaria* and to *M. edulis* were not recovered on later examination of the recipients. Apparently, the larvae were passed from the mollusks and lost in the running sea-water. Attempts to infect subsequent hosts with cercaria and metacercariae from *M. arenaria* and *H. arctica* have been disappointing.

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HORACE W. STUNKARD[1] AND JOSEPH R. UZMANN[2]

U. S. Fish and Wildlife Service

Historical Review

The genus *Gymnophallus* was erected by Odhner (1900) to contain *Distomum deliciosum* Olsson, 1893 and other small species from the gall bladder, intestine and bursa Fabricii of shore-birds. Subsequent observations have shown that the asexual generations of these worms occur in bivalve mollusks and that the cercariae, which are produced in sporocysts, belong to the Dichotoma group of furcocercous larvae. Typically, these cercariae have eye-spots and short bifid tails, although either or both may be reduced or absent. *Cercaria dichotoma* emerges and swims as a furcocercous larva. In certain species the tail undergoes regression and is lost before the larva emerges from the sporocyst whereas, in others, apparently no tail is formed. On emergence from the first intermediate host, the cercariae attach to the mantle or body wall of bivalve or gastropod mollusks where as unencysted metacercariae, they develop to almost definitive size. The metacercariae may produce lesions on the mantles of their hosts and such injuries stimulate proliferation of tissues, especially of the secreting layer of the mantle, and deposition of nacreous material. Despite the observations of many investigators over a period of more than fifty years, no complete life-history has yet been worked out and the specific relations between particular cercariae, metacercariae, and sexually mature worms remain undetermined.

The presence of pearly formations in the mantle of *Mytilus edulis* has been known for at least three hundred years. According to Giard (1907), they were reported by Olaus Worm in 1655 from mussels taken at Roeskild, near Copenhagen. Robert Garner observed them in *M. edulis* from the English coast and he (1872) recognized that they were formed as a reaction by the mollusk to a small distome parasite on the mantle. Baron d'Hamonville (1894) found pearls (*sans valeur*) in *M. edulis* at Billiers (Morbihan) France, although the infection was limited to the area of the port. Giard (1897) reported small distomes, often associated with irregularly shaped calcareous deposits, between the mantle and shell of *Donax trunculus* L., *Tellina fabula* Gronov, *Tellina tenuis* DaCosta and *Tellina solidula* (= *T. balthica* L., *ex parte*) from Boulogne-sur-Mer. The worms were 0.5 mm. long, with rudiments of testes, but no ovary, and Giard suspected that they might be stages in the life-cycle of *Brachycoelium luteum* (van Beneden), a parasite of the common dogfish, *Scyllium canicula*. The larger specimens were often less active, more opaque, and filled with sporozoans (Glugidées). Dubois (1901) studied the parasites of *M. edulis* at Billiers and found them in reddish brown spots,

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which were the loci of pearl formation. The worms measured 0.4–0.6 mm. in length and for them he proposed the name, *Distomum margaritarum*. He found the same or a similar parasite in *Mytilus galloprovincialis* from the coast of Provence.

Jameson also studied the parasites at Billiers; he (1902) described and figured the worms which he stated closely resembled *Distomum somateriae*, whose mature stages had been described by Levinsen (1881) from the intestine of the eider duck, *Somateria mollissima*, taken near Egedesminde, Greenland. He recalled that Möbius (1857) had reported a trematode associated with pearls in the pearl oyster, *Margaritifera margaritifera*, from the west coast of N. America. Following the action of Stossich (1899), Jameson referred the species from *M. edulis* to *Lecithodendrium* Looss, but misspelled the name, *Leucithodendrium*. He reported that he had found larvae, similar to those in *M. edulis*, in sporocysts in *Tapes decussatus* and that he had infected *M. edulis* with these sporocysts. The larvae in the sporocysts were tailless; they differed from those in *M. edulis* only in their smaller size, paler color, more distended excretory organs and empty gut, and in the possession of special sense organs and eyes. The sporocysts were present in all of almost 200 *Tapes* examined, located chiefly in the margin of the mantle where it is attached at the pallial line. The sporocysts were spherical to oval, about 0.5 mm. in diameter, with six to ten cercariae in each. Jameson also reported that *M. edulis* from Piel, near Barrow, Lancashire, England, were heavily infected with distome larvae, similar to those at Billiers, but that *Tapes* was not present at Piel. The sporocysts at Piel were found in *Cardium edule*. *Mytilus edulis* at Piel were exposed with specimens of *Tapes decussatus* from Billiers, with an apparent increase in the number of parasites. Returning to Billiers, Jameson found every specimen of *Oidemia nigra* heavily infected with *L. somateriae*. The worms were present throughout the length of the intestine. He described and figured the adult stage of *L. somateriae*; the worms were 0.2 to 0.55 mm. in length, about one-half the size of the larvae in *M. edulis*, and Jameson stated that the striking likeness except for size, between the larvae from *M. edulis* and *L. somateriae* and the occurrence of the latter in two species of birds that are known to feed *par excellence* on mussels is almost sufficient to prove their identity without the feeding experiment. He described the manner in which the mantle of *M. edulis* forms a sac around the trematode larva and deposits the nacreous material. Giard (1903) confirmed the observations of Jameson on pearl formation and, since pearls are the sarcophagi of trematode larvae, proposed their production by artificial means.

The first report of the asexual generations of *Gymnophallus* was an incidental footnote by von Siebold (1837) who found the sporocysts and cercariae in *Macoma balthica*. Lebour (1904) described the sporocysts in the liver and about the intestine of *Cardium edule* as (p. 83) "oval, pointed at one extremity, with two conspicuous black eyes, the other end is rounded and the whole body is covered with cilia which are constantly in motion in the living animal. The sporocyst may contain three different elements, (1) spherical masses full of smaller spheres, (2) the same but with two of these masses in one envelope, (3) minute sporocysts exactly like itself and containing small spheres." Miss Lebour regarded the "sporocysts" as the first larval stage of an echinostome species whose metacercariae she found encysted in the foot of the mollusk but whose cercarial stage was not discovered. In a footnote she added (p. 84), "since writing this I have discovered another stage

of the worm in the liver of the cockle, of which particulars will be given later." In the report for 1905, Miss Lebour recognized that the "sporocysts" from the liver of *C. edule* were not related to the echinostome larvae in the foot, for which she had postulated the life-cycle. She stated that *C. edule* harbors the sporocyst stage of three species of trematodes; the one she reported in 1904, the second is "the sporocyst and cercaria stage of the 'pearl trematode' which is the cause of pearls in the mussel," and the third species was described as very contractile and of various shapes, without eyes and not ciliated. The report contains a brief description and figure of a "cercaria" from *Tellina tenuis* and *Donax vittatus* from the Alnmouth sands. From the figure, it is clear that the supposed "cercaria" is a gymnophallid metacercaria.

Johnstone (1905), in *C. edule* at Piel, found a fork-tailed larva which he described and figured as *Cercaria fissicauda* La Valette. It was probably not the tailless, ocellate species that had been reported by Jameson and was possibly *Cercaria dichotoma* Müller. This latter species, found free in the Mediterranean near Nice by Müller and described in La Valette (1855), was reported from the marine lamellibranch, *Scrobicula tenuis* by Villot (1875), but Villot (1878) assigned the larvae to *Cercaria fissicauda* La Valette, 1855. As noted by Pelseneer (1906), *C. fissicauda* was described from a fresh-water gastropod, *Lymnaea stagnalis*, and Villot's (1878) designation was obviously an error. The cercaria described and figured as *C. fissicauda* by Villot (1878) was identified as *C. dichotoma* by Pelseneer. Pelseneer described, as *C. dichotoma*, a species which he found in *Tellina solidula* from deep water near Boulogne-sur-Mer. The cercariae developed in short, nodose, colorless sporocysts and closely resembled the figures of *C. dichotoma* as given by La Valette and that of the species by Villot (1878) which he designated as *C. fissicauda*, but which he previously (1875) had identified as *C. dichotoma*. Pelseneer also referred to *C. dichotoma* an unnamed cercaria described by Huet (1888). Huet found this species in *Cardium edule* on the coast of Normandy and his description clearly contravenes its identity with *C. dichotoma*. According to Huet, the sporocysts were short, compact, spherical to pyriform, with the anterior end elongated in the form of a neck. The sporocysts were covered with cilia and swam freely. Immature sporocysts were 0.2 mm. in length and grayish in color; older ones, 0.3 mm. in length, were yellowish and the birth-pore, situated at the anterior end, was surrounded by five tubercules, below which there was a crown of verrucosities and the intervening area was covered with fine, stiff bristles. Mature sporocysts, 0.5 mm. long, were yellow and contained a few distomid cercariae with bifid tails, but on completion of development the tails were shed and the cercariae emerged from the sporocysts. The figures of Huet show that the cercaria is a gymnophallid larva, but it is not *C. dichotoma*, which emerges and swims as a furcocerous larva. Pelseneer also described a new species, *Cercaria syndosmyae*, from *Syndosmya alba* at Boulogne-sur-Mer. The sporocysts were 0.75 to 1.0 mm. in length, cylindrical, without constrictions. The cercariae were elongate, the acetabulum, near the middle of the body, was slightly larger than the oral sucker; the ceca were short, globose, and the cephalic glands were straight, moderately long. The furcae were longer than the stem of the tail. Young distomes, of corresponding morphology, were found often between the mantle and shell of *Donax* and other bivalves in the same locality. Odhner (1911a) postulated that *C. syndosmyae* is a larval stage of *Haplocladus minor*. This suggestion

appears more credible since Cable (1953) included the Haplocladinae and Gymnophallinae as subfamilies in the family Fellodistomatidae.

Meanwhile Odhner had studied the trematodes of marine birds. He (1900) re-described and figured *Distomum deliciosum* Olsson, 1893, from the gall bladder of three species of *Larus*, which he named as type of a new genus, *Gymnophallus*. In the new genus he included *G. somateriae* (Levinsen, 1881) from the intestine of *Somateria mollissima*, *G. micropharyngeus* (Lühe, 1898) from the gall bladder of a North African flamingo, and two new species, *G. choledochus* from the gall bladder of *Vulpanser tadorna*, and *G. bursicola* from the bursa Fabricii of *Somateria mollissima*. In a later paper, Odhner (1905) re-described *G. somateriae* and commented on the findings of Jameson, in which the metacercariae from *M. edulis* were identified as larval stages of *G. somateriae*. Since the larvae from *M. edulis* were much larger than the sexually mature *G. somateriae*, Odhner contended that they could not be identical and that the material of Jameson represented two closely related species. The larger species, whose larvae induced pearl formation in *M. edulis*, was referred to *G. bursicola* since in morphology it agreed completely with the description of that species. The smaller mature worms from *Oidemia nigra*, according to Odhner, belonged to a different and unnamed species. The metacercariae described by Jameson from *M. edulis* agreed completely with others found by Odhner in the original material of *Saxicava rugosa* (= *Hiatella rugosa*) collected by Levinsen at Egedesminde, Greenland and which as noted by Levinsen, differed from *G. somateriae* in total size and size of suckers. Odhner noted differences between *G. somateriae* and the mature worms found by Jameson in *Oidemia nigra* at Billiers, which he postulated belong to a new and as yet unnamed species. Discussing the genus *Gymnophallus*, Odhner stated that it could not be included in any of the previously recognized subfamilies, and it was designated as type of a new subfamily, Gymnophallinae.

Nicoll (1906) examined *Cardium edule* at St. Andrews, Scotland; from May to July no infection was noted in several hundred individuals; later, sporocysts similar to those reported by Jameson in *Tapes* were found abundantly in the midline, dorsally, just over the posterior border of the liver. Individual sporocysts appeared as yellow spots of various sizes in an opaque, whitish mass which measured about four by three millimeters. Each sporocyst contained from two to fifty cercariae. The cercariae were tailless, 0.11 to 0.28 mm. in length, ocellate; the oral sucker (with minute papillae) about twice the size of the acetabulum which was situated just anterior to the bifurcation of the excretory vesicle. The testes were lateral, somewhat behind the acetabulum. Nicoll kept cockles (*C. edule*) and mussels (*M. edulis*) in the same tank for some time, but no infection of the mussels was noted.

Giard (1907) reviewed previous work on the trematodes which induce pearl formation in marine lamellibranchs; he reported that a worm, similar to the one described by Pelseneer, occurs frequently in *M. edulis* at Wimereux, near Boulogne-sur-Mer; that this species, named *D. margaritarum* by Dubois (1901) is probably identical with the one found in *Saxicava rugosa* by Levinsen and a stage in the life-cycle of *G. bursicola*. Giard also reported another and different distome which occurs abundantly "dans les *Donax* et les *Tellines* du Port de Boulogne" and which agrees with *G. somateriae* and differs from the parasite in *Mytilus*. *Oidemia nigra*, the pochard, was listed as the probable final host. Lebour (1905) had re-

ported and figured a "cercaria" which occurred in *Tellina tenuis* and *Donax vittatus*, which she identified as the species described by Giard (1897) and regarded by him as possibly a larval stage of *Brachycoelium luteum*.

Nicoll (1907) described *Gymnophallus dapsilis* n. sp., from the bursa Fabricii of the scoters, *Oidemia fusca* and *Oidemia nigra*. This species differs from *G. bursicola* and other species of *Gymnophallus*, in that the vitellaria are anterior to the acetabulum. The worms were small, 0.84 to 1.13 mm. in length; however, Nicoll suggested that they may be adults of the species whose larvae occur in *M. edulis*.

Lebour (1908) described three gymnophallid cercariae (actually metacercariae): *C. glandosa* from *Paludestrina stagnalis* (a gastropod) which measured 0.2 mm. in length and had many large glands in the anterior part of the body; *C. macomae* from *Macoma balthica*, which measured 0.7 mm. long; and *C. strigata*, the species which Giard (1897) had regarded as the larva of *Brachycoelium luteum* and (1907) as that of *Gymnophallus somateriae*. Miss Lebour reported that it occurs very commonly in *Tellina tenuis* and rarely in *Donax vittatus* at Alnmouth. This is the same species reported by Lebour in 1905; the worms measured 0.3 to 0.4 mm. in length; the oral sucker was 0.09 mm. in diameter, and the acetabulum 0.05 mm. Miss Lebour noted that Pelseneer had described and figured what was evidently the same larva, and which he regarded as a later stage of the furcocercous cercaria named by him, *C. syndosmyae*. But in *C. syndosmyae* the suckers are nearly equal in size which renders their identity unlikely, and the larvae found in sporocysts in *Cardium edule* and *Tapes decussata* by Jameson, Nicoll and Lebour were tailless. Miss Lebour stated that *C. strigata* is broader than *C. somateriae* and the striations produced by the rows of spines are more conspicuous. Furthermore, ducks seldom feed at Alnmouth, and the adult stage of these parasites is probably in gulls; possibly it is *G. deliciosus*. Miss Lebour also described a larva which she identified as *Cercaria dichotoma* Müller, from the small bivalve, *Scrobicularia tenuis*. The figure shows that it is the cercarial stage of a species of *Gymnophallus* and Miss Lebour believed that the same species had been recorded by Pelseneer from *Tellina solidula* (= *Macoma balthica*), by Johnstone from *Cardium edule* on the Lancashire coast, and by Huet in *C. edule* in Normandy.

Lebour (1912), in a review of the British marine cercariae, recognized five gymnophallid cercariae (actually metacercariae): (1) *Cercaria margaritae*, the pearl trematode of Jameson (1902), which occurs in sporocysts in *C. edule* and *Tapes decussata*; (2) *Cercaria scrivenensis* sp. inq., based on two specimens from *Tapes pullastra* at Loch Scriven, the Clyde, but not well characterized; (3) *Cercaria glandosa* Lebour, 1908; (4) *Cercaria macomae* Lebour, 1908; and (5) *Cercaria strigata*, Lebour, 1908. Apparently Miss Lebour was not yet aware that the larvae she regarded as cercariae were really unencysted metacercariae, since she noted that *Cercaria dichotoma*, which she described and figured, is closely allied in structure to *Gymnophallus* but, because of its forked tail, she placed it in a separate group. *Cercaria margaritae* has eye-spots and according to Jameson develops in sporocysts in the edges of the mantle of *Tapes decussatus* and *Cardium edule* whereas Nicoll and Lebour reported this species from sporocysts in jelly-like masses under the umbo of *C. edule*. These differences suggest that two distinct species were regarded as identical.

Sinitsin (1911) described sporocysts from *Syndosmya alba* of the Black Sea

as *Cercaria discursata* n. sp. The sporocysts were simple, saccate, in the liver and gonad; the cercariae 0.06 mm. long with a bifid tail somewhat longer, normally shed in the sporocyst, but used in sluggish swimming when the cercariae are released from the sporocyst. According to Sinitsin, some of the larvae remain as unencysted metacercariae in *S. alba,* while others leave and migrate to various species of mollusks. They attack the tissues but do not encyst and increase about four times in size. In the same paper Sinitsin described *Adolescaria perla* from various mollusks, mostly near the gill plates of *M. edulis* and unidentified species of *Venus.* From the descriptions and figures of Sinitsin, both of these species can be identified as gymnophallids, and indeed, they may be stages in the life-history of a single species.

Stafford (1912) reported sporocysts and cercariae in *Mya arenaria* of the Gaspé Bay region of Canada. The venter of the clam was distended, soft, translucent, pale greenish yellow in color with hundreds of sporocysts, each containing about twenty fully-formed, forked-tailed cercariae; the body of one cercaria measured 0.138 by 0.082 mm. From the surface of the mantle of *M. arenaria* and *M. edulis,* Stafford reported metacercariae which measured 0.078 by 0.056 mm. These specimens were similar to those reported by Levinsen from the intestine of *Somateria mollissima* which occurs on the Gaspé, but since they were smaller than the cercariae from *M. arenaria,* Stafford concluded that they did not belong to the same species.

Jameson and Nicoll (1913) reviewed the question of pearl formation in *M. edulis* and the identity and life-history of the trematode larvae which are the inciting agents. Jameson's earlier experiments were not controlled; the form described by him (1902) as *G. (Leucithodendrium) somateriae* was now described as *Gymnophallus oedemiae.* Since the gravid worms are smaller than the metacercariae in *M. edulis,* these authors reasoned that they cannot be the adult stage of that species. They stated that the metacercariae in *M. edulis* may be *G. bursicola* as believed by Odhner or possibly *G. dapsilis* Nicoll. They postulated that the sporocysts and cercariae in *Tapes decussatus* are *G. bursicola*; that those in *C. edule* are *G. dapsilis*; and that metacercariae of both may occur in *M. edulis.* Although specimens of *Oidemia nigra* were naturally infected with a species of *Gymnophallus,* metacercariae from *M. edulis* did not develop in *Oidemia nigra* or *Fuligula (Nyroca) ferina.* Jameson and Nicoll recognized six species; *G. bursicola* Odhner; *G. dapsilis* Nicoll; and four new species; *G. oedemia, G. affinis, G. macroporus* and *G. ovoplenus,* all from the intestine of *O. nigra.*

Dollfus (1923) studied the metacercariae from *Mytilus galloprovincialis* described earlier by Dubois (1901). He found the worms to measure 0.23 to 0.27 mm. in length, with the oral sucker about twice the size of the acetabulum. They were similar to the *Adolescaria perla* of Sinitsin and to others which Dollfus had observed between the mantle and shell of *Tapes pullastra* on the English channel. For them he proposed the name, *Gymnophallus duboisi* n. sp.

Odhner (1900) had described *Gymnophallus choledochus* n. sp. on the basis of sketches made by Jägerskiöld, of a single specimen (then lost) from the gall bladder of *Vulpanser tadorna.* He (1905) re-described the species from specimens taken from the gall bladder of *Somateria mollissima* and *Somateria spectabilis* from East Greenland. The worms were pyriform, 0.9 to 1.1 mm. long, 0.35 to

0.50 mm. wide, with the acetabulum near the middle of the body, ceca which extended to the middle of the body, and testes lateral, postcecal. Isaitchikow (1924), apparently unaware of Odhner's re-description, reported *G. choledochus* from the gall bladder of *Aytha* (*Nyroca*) *ferina* from the Crimea. He noted that the distribution of the species is not restricted to Scandinavia, but extends to the Black Sea. He found that the coils of the uterus may fill the body from the oral sucker to the reproductive glands, that the topography of the genital organs is not fixed, the variations are numerous and very inconstant; eight different types were depicted by figures.

Palombi (1924) re-described *Cercaria margaritarum* Dubois, 1901 (actually a metacercaria) and stated that *G. duboisi* Dollfus, 1923 is a synonym. Later Palombi (1934) described and figured the metacercariae of *Gymnophallus strigata* (Lebour) and *Gymnophallus megacoela* n. sp. In an article by Fujita (1925), Dollfus described *Gymnophalloides tokiensis* n.g., n. sp., a gymnophallid metacercaria from the surface of the mantle of the Japanese oyster, *Ostrea gigas*. The text was translated by R. Ph. Dollfus, who added notes, diagnoses, and a bibliography. In this species the genital pore is located some distance anterior to the acetabulum and for it Dollfus provisionally proposed a new genus, *Gymnophalloides*. In the paper, Dollfus described a second species, *Gymnophalloides tapetis*, a metacercaria from *Tapes pullastra* at Saint Vaast-la-Hougue (Manche), which he noted is very similar to *Adolescaria perla* Sinitsin.

Cole (1935) reported an "orange sickness of mussels" at the Conway station on the coast of North Wales. According to him (p. 276), "The infected specimens were found without difficulty as the mantle is a vivid marigold to blood-orange due to the presence of innumerable sporocysts." The sporocysts were present also throughout the body of the mollusk. They were oval, bright orange, thin-walled, moderately contractile and measured about 1.1 mm. by 0.45 mm. They contained tailless cercariae which were described as a new species, *Cercaria tenuans*. The cercaria measured up to 0.3 mm. in length when extended; the oral sucker was 0.05 mm. and the acetabulum 0.07 mm. in diameter. The cercariae were without spines and died soon after emergence, which indicates an immature condition. In one mussel, Cole reported similar sporocysts in the digestive gland, but they contained daughter sporocysts and no cercariae. This observation led to the suggestion that *M. edulis* acquires the infection by way of the intestine. Cole predicated that the species described by him is probably identical with the one reported by Miss Atkins (1931) in 2.16 per cent of over ten thousand mussels from the estuary of the Camel, near Padstow.

Young (1936) described fork-tailed cercariae taken in a tow net in the Bering Sea, 15–65 kilometers from the nearest land. The larvae were without eyes or spines, 0.4 mm. long; the oral sucker was 0.085 mm. and the acetabulum 0.09 mm. in diameter. The specimens were reported to agree best with *C. syndosmyae* Pelseneer, and they may be a species of *Gymnophallus*.

Markowski (1936) described *Cercaria baltica*, a furcocercous species from sporocysts in *Macoma balthica*. The sporocysts were long, cylindrical, whitish, slowly motile; 1.2 by 0.15 mm., each contained from two to fifty cercariae. The cercariae measured in microns; body length, 133; tail-stem, 90; furcae, 38; oral sucker, 11; acetabulum, 44 by 30; cecal length, 52. The measurements as given do not agree with his Figure 6, in which the oral sucker is approximately

the same size as the acetabulum. In *C. baltica* the entire surface of the body, including the tail-stem and furcae, is spined, there are four pairs of glands near the oral sucker, and the ceca extend to the anterior edge of the acetabulum which is slightly behind the middle of the body. Markowski recognized four species in the Dichotoma group of cercariae; *C. dichotoma* Müller, *C. syndosmyae* Pelseneer, *C. discursata* Sinitzin, and *C. baltica* n. sp. From the same host Markowski described two metacercariae: *Metacercaria morula*, in which a large number of larvae were enclosed in a single cyst; and *Metacercaria mutabilis* which are about three times as large as the former species and occur unencysted on the mantle or in folds of it.

Cole (1938) reported a brown mass below the hinge of *C. edule*, situated in a wedge-shaped cavity which, when torn, liberated thick-walled, colorless, immobile sporocysts and brown granules. The tailless cercariae, named *C. cambrensis*, were spined and measurements in millimeters were: length, 0.27–0.32; oral sucker, 0.04; acetabulum, 0.03; pharynx, 0.015. The acetabulum was about one-third of the body length from the posterior end; the ceca were reported to extend to the level of the posterior border of the acetabulum but are preacetabular in the figure. The cercaria was similar to *C. margaritae* of Jameson (1902) as described by Lebour (1912) and Jameson and Nicoll (1913), but differed in the absence of eye-spots and sensory papillae.

Rees (1939) re-described *Cercaria strigata* Lebour, 1908, which was actually a metacercaria found by Miss Lebour in *Tellina tenuis* and *Donax vittatus* at Alnmouth, Northumberland. Presumably it was identical with the unnamed larva found by Giard (1907) from the same hosts. Miss Rees found the cercariae in thin-walled, colorless sporocysts in the digestive gland of *C. edule*. The cercariae were not described other than the statement that they were the same as the metacercariae. The excretory vesicle extended to the region of the oral sucker and the anterior ends were bifid. The flame-cell formula was $2[(2+2)+(2+2)]$. *Cercaria strigata* was distinguished from *C. margaritae* of Jameson by absence of eye-spots and bristles and location of sporocysts, which in the former were just below the hinge. It differs from *C. cambrensis* which develops among brown granules in thick-walled sporocysts. According to Rees, *C. strigata* could be the larva of *Gymnophallus macroporous* Jameson and Nicoll, 1913 from *Oidemia nigra* but more likely is the larva of *G. deliciosus* which was found abundantly in the gall bladders of gulls in the region. She suggested that *C. cambrensis* is the cercarial stage of the metacercaria in *M. edulis* and identical with *Gymnophallus margaritarum* (Dubois).

Yamaguti (1939) described *Gymnophallus macrostoma* from the intestine of *Melanitta (Oidemia) nigra americana* (Swainson) from Korea. According to Yamaguti, the new species differs from *G. affinis* and *G. macroporus* in size of eggs and position of the ovary; it resembles *Gymnophalloides tokiensis* Fujita, 1925, a metacercaria, but identity must await experimental evidence. Yamaguti re-described *G. bursicola* from *Melanitta fusca stejnegeri* and *Melanitta nigra americana*; variations in morphology led him to regard *G. dapsilus* Nicoll as probably identical with *G. bursicola.*

Ogata (1944) found metacercariae in *Paphia (Ruditapes) philippinarum, Laternula kamakurama* and *Tellina* spp. which were raised to adults in cats and mice. The mature worms were identified as *G. bursicola.*

Uzmann (1952) described *Cercaria myae* from the gonads and digestive gland of *Mya arenaria* at Newburyport, Massachusetts. The sporocysts were clavate, unpigmented, motile, with thin walls and apical birthpores; they measured 0.21 to 0.60 mm. in length. He suggested that this is the same species reported by Stafford (1912) from the same host in Canada. The body of the cercaria is 0.12 to 0.25 mm. long; the tail-stem is about one-third the body length with furci slightly longer than the stem and spined at the tips.

Dubois, Baer and Euzet (1952) described *Cercaria mathiasi*, a furcocercous cercaria from the Mediterranean, which was identified as a species of *Tergestia*. The cercaria was included in a group with *Cercaria haswelli* Dollfus, 1927, which Odhner (1911b) had recognized as a species of *Tergestia*, and *C. dichotoma* La Valette. Although *C. dichotoma* has been widely accepted as a gymnophalline larva, the relation to *Tergestia* does not appear unlikely since Cable (1953) has included the Haplocladinae (which includes *Tergestia*) and the Gymnophallinae in the family Fellodistomatidae.

Hutton (1952) studied the gymnophallid parasites of *C. edule* at Plymouth, England. He described a new species, *Cercaria fulbrighti*, which developed in motile, irregularly shaped sporocysts with birthpores at the tips of snout-like protrusions. The sporocysts were found in the digestive gland, gonad, and dorsal part of the foot. Young cercariae in sporocysts have forked tails, which degenerate when the larvae are about one-half grown. The cercariae lack eye-spots, are spined, while the excretory vesicle extends parallel to the ceca and is not lyre-shaped. The mature cercaria agrees closely with *G. choledochus* and differs from *C. margaritae* which has eye-spots and in which the excretory vesicle is lyre-shaped and extends to the oral sucker. He reported that the excretory system has thirteen flame-cells on each side of the body. It is possible that the cilia in the common collecting duct were counted as the thirteenth flame-cell. Hutton differentiated between *C. fulbrighti* and *C. cambrensis* which he found in the same host species. He noted resemblances between *C. fulbrighti* and *C. dichotoma* as described by Pelseneer (1906) and Lebour (1908), but certain differences led him to regard them as distinct species.

Hutton (1953) described *Cercaria reesi* from *Hiatella arctica* and *Hiatella striata* taken at Drake's Island and Plymouth Sound. The sporocysts were ovoid to sausage-shaped, 0.32 to 0.80 mm. long and 0.196 to 0.352 mm. wide. The cercariae were fork-tailed, non-oculate, with two pairs of penetration glands. The flame-cell formula was $2[(2 + 2) + (2 + 2)]$, a total of 16 cells, the same as Rees (1939) had found in *C. strigata*. The oral sucker was surrounded by two pairs of protrusible spines and six tubercules. Hutton stated that *C. reesi* closely resembles *C. discursata* Sinitsin and *C. myae* Uzmann, 1952, and that all are probably members of the genus *Gymnophallus*.

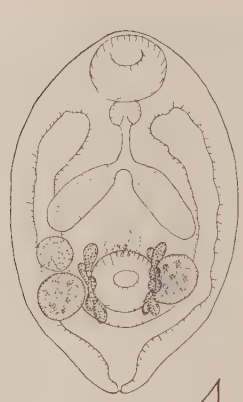
Brinkmann (1956) in a study of the Trematoda of Iceland, reported a single unidentified specimen of *Gymnophallus* from the gall bladder of *Somateria mollissima* and another from the gall bladder of *Clangula hyemalis* which he described as a new species, *Gymnophallus bilis*. He noted that except for the location of the genital pore the latter worm agrees entirely with Levinsen's (1881) description of *G. somateriae*, which differs in essential respects from Odhner's re-description of that species, based on new material and possibly on a different species of *Gymnophallus*.

Gymnophallid trematodes have been known for more than a century. The first of these worms to be discovered were metacercariae from the mantle of *Mytilus edulis*, and sporocyst stages were reported by von Siebold (1837) in *Macoma balthica* from the coast near Danzig. Sexually mature specimens were described and named by Levinsen (1881) from the digestive tract of eider ducks, *Somateria mollissima*. Subsequently, worms have been reported from the gall bladder, intestine, ceca, and bursa Fabricii of different species of birds. Twelve specific names have been applied to these sexually mature specimens but the species are not clearly distinguished and the validity of certain of them is doubtful. During this time, cercarial stages have been described from a variety of bivalve mollusks, but frequently cercarial and metacercarial stages have been mistaken for one another and there is no reliable information to identify any cercaria with its metacercarial or adult stage. Metacercariae occur frequently in bivalve and rarely in gastropod mollusks, but knowledge of their previous larval or final sexually mature stages is completely lacking. The situation is chaotic and one of utter confusion.

Even the systematic position of the subfamily Gymnophallinae is equivocal. It was erected by Odhner (1905) who postulated relationship to the Heterophyidae but admitted (p. 314), "Die Frage, wo diese Unterfamilie zu placieren ist, kann dagegen nur der Gegenstand sehr unsicher Vermutungen sein." Fuhrmann (1928) included it in the family Acanthostomidae; Dawes (1946) in the family Microphallidae; and Uzmann (1952) suggested its probable relationship to the family Brachylaemidae. Cable (1953) transferred the Gymnophallinae to the family Fellodistomatidae, in the superfamily Brachylaemoidea. This action was based on the discovery of the first life-cycle in the subfamily, that of *Parvatrema borinqueñae*, a new genus and species from Puerto Rico. The unencysted metacercariae from the snail, *Cerithidea costata*, developed to maturity in baby chicks and since sandpipers, plovers, terns and herons of the region did not harbor gymnophalline trematodes, Cable postulated that the natural hosts were migrant ducks. Small, furcocerous cercariae, produced in sporocysts in *Gemma purpurea*, were recognized as the antecedent larval stage of the species. In the same paper, Cable suggested that *Metacercaria morula* of Markowski (1936) may be a cercaria, and that *Cercaria baltica* may be conspecific with *Metacercaria mutabilis* from the same host. This species is probably the one found by von Siebold in the same host a century before.

Present Project

For some years the U. S. Fish and Wildlife Service has been concerned with the attrition in stocks of the soft-shelled clam, *Mya arenaria*, along the New England coast. Reduction in numbers of these clams was reported by Smith (1950), Smith and Chin (1951), and Glude (1955). The junior author began a study of the significance of parasitism in relation to this problem at Newburyport, Massachusetts and continued it at Milford, Connecticut. He (Uzmann, 1952) published a description of the sporocysts and cercariae found in *M. arenaria* at Newburyport, Massachusetts. The larvae, named *Cercaria myae*, emerge from the sporocysts and swim in the sea; they have forked tails but no eye-spots. The amount of living material was limited and no infection experiments were attempted. Uzmann also found sporocysts and cercariae in *Hiatella arctica* of the Boothbay Harbor area of Maine, but they were not reported. In addition, Uzmann (1953) described



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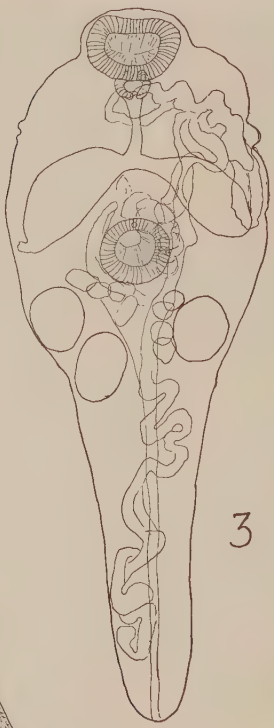

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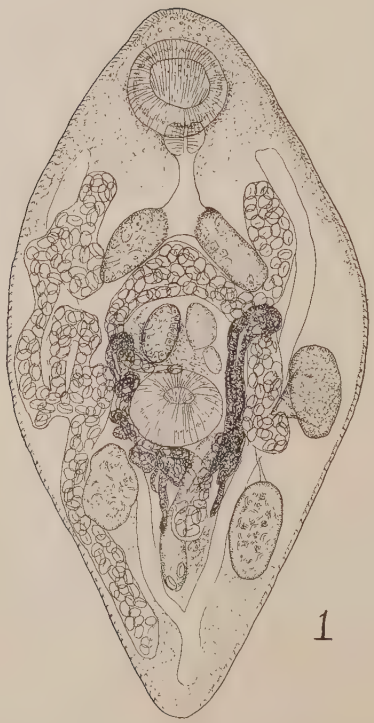

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PLATE 1

sporocysts and cercariae from *Mytilus edulis* taken in Long Island Sound, New York; this species, named *Cercaria milfordensis*, was referred tentatively to the genus *Proctoeces*. Metacercariae had been found in lesions, and associated with pearly deposits, in the mantle of *M. edulis* collected in the region of Newburyport, Massachusetts.

In collaboration with the senior author, attempts were made to determine the adult stage of the metacercariae from *M. edulis*. Specimens were fed on February 24, 1951 to a hamster and the animal was sacrificed on March 3, 1951. Sexually immature worms (Fig. 4) were recovered, which manifested diagnostic characteristics of the genus *Gymnophallus* and it appeared that the natural definitive hosts were mollusk-eating birds. Accordingly, metacercariae (Fig. 9) were fed to domestic chicks and ducklings, but no infection was obtained. Eggs of eider ducks, sent from Boothbay Harbor, Maine, were incubated in the laboratory at New York University and metacercariae, fed June 1, 1951 to recently hatched eider chicks, developed during ten days in the intestine to sexual maturity (Fig. 5). These worms belong to the genus *Gymnophallus*, but because specific descriptions are so inadequate, identification is tentative. Subsequently, the junior author was transferred to the Seattle, Washington, Laboratory of the U. S. Fish and Wildlife Service and the senior author, on retirement from teaching at New York University, was assigned to a study of the parasites of clams and of their predators. The green crab, *Carcinides maenas*, an important predator, harbors the metacercarial stages of a digenetic trematode whose life-history was worked out (Stunkard, 1957) and the adults were identified as *Microphallus similis* (Jägerskiöld, 1900). Returning to the investigation of the sporocysts and cercariae in *M. arenaria,* a study of the gymnophallid trematodes was resumed. For whole-hearted cooperation and for material, we are indebted to Walter R. Welch, Chief of Clam Investigations, Boothbay Harbor, Maine and members of his staff. In the summer of 1957 sporocysts and cercariae were found by the senior author in the digestive gland of *Gemma gemma* taken at Boothbay Harbor and unencysted metacercariae from the mantle of *G. gemma* developed to sexual maturity in the intestine of *Somateria mollissima.*

Most of the previous work on gymnophallid trematodes has been done in Europe; the parasites have been reported from different locations in different hosts, but specific determination on the basis of existing descriptions is virtually impossible. A satisfactory solution of the difficulties requires controlled experiments to discover and relate successive stages in the life-cycles of individual species. Certain questions are pertinent to a consideration of the problem of specificity: (1) to what extent can one species of *Gymnophallus* infect different primary, secondary, and definitive hosts; (2) are the gymnophallids in gulls, eider ducks, and

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Explanation of Plate I.

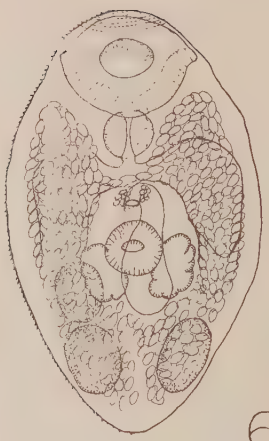
Figure 1. Adult from the bursa Fabricii of *S. mollissima*, Boothbay Harbor, Maine. Natural infection, specimen 1.0 mm. long, fixed, stained and mounted, ventral view.

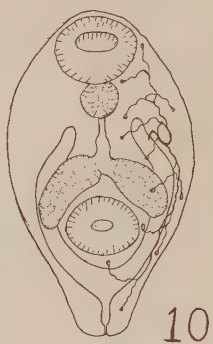
Figure 2. Adult from the gall bladder of *S. mollissima*, Boothbay Harbor, Maine. Natural infection, specimen sketched alive, 1.3 mm. long, dorsal view.

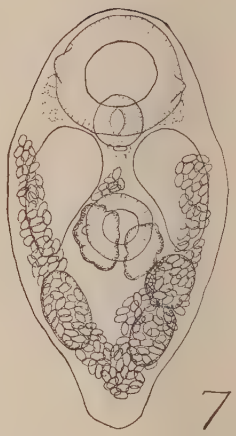
Figure 3. Same specimen shown in Figure 2, fixed, stained and mounted, 1.7 mm. long.

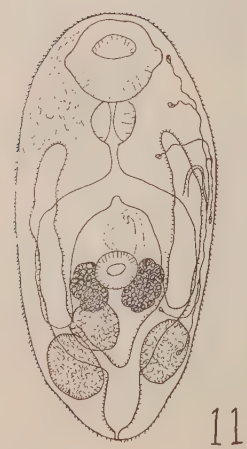
Figure 4. Immature specimen from the mantle of *M. edulis*, recovered from the intestine of a hamster seven days later, somewhat flattened, 0.43 mm. long, ventral view.

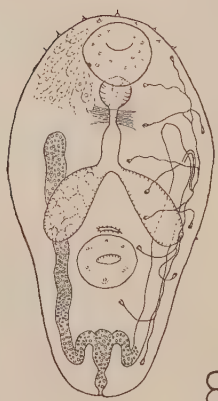
Figure 5. Mature but not fully gravid specimen, removed from the mantle of *M. edulis* and developed ten days in a recently hatched chick of *S. mollissima*, 0.72 mm. long, dorsal view.











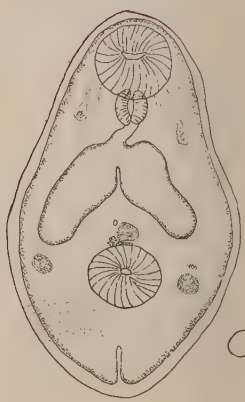


PLATE II

FIGURE 6. Adult, flattened specimen from the intestine of *S. mollissima*, experimental infection, after feeding metacercariae from *Gemma gemma*. Specimen 0.24 mm. long, ventral view.

FIGURE 7. Another specimen, same infection as before, worm not flattened, 0.22 mm. long, ventral view.

FIGURE 8. Metacercaria from *Mya arenaria*, Woods Hole, Mass., 0.9 mm. long, excretory system added from sketches made when worm was alive.

FIGURE 9. Metacercaria from *Mytilus edulis*, Newburyport, Mass., same species as Figures 4 and 5. Specimen 0.46 mm. long.

other shore-birds members of the same or different species; (3) are the worms in the gall bladder, the intestine, the ceca, and bursa Fabricii of eider ducks members of the same or different species; (4) do the asexual generations of sporocysts in *Gemma gemma*, in *Hiatella arctica*, *Mytilus edulis*, and *Mya arenaria* belong to the same or different species; (5) which, if any, of the reported metacercariae and adults are later stages in the life-cycle of *Cercaria myae?* In an attempt to find answers to these questions the following procedures were devised: (1) collect and compare worms from the several locations in eider ducks and herring gulls (*Larus argentatus*); (2) determine whether the larvae (miracidia) in the eggs of these worms are mature and infective or whether the eggs need to be embryonated; (3) try to infect the different species of bivalve mollusks with eggs from worms taken from different hosts and different locations; (4) attempt transplantation of metacercariae from each species of bivalve to each of the others; (5) attempt infection of eider duck chicks with metacercariae from *G. gemma*, *H. arctica* and *M. arenaria*; (6) attempt infection of mammalian hosts with metacercariae from each of the molluscan hosts.

The material so far available [3] consists of adult worms from natural infections in the bursa Fabricii and gall bladder of *Somateria mollissima* taken at Boothbay Harbor, Maine and others from experimental infections of the intestine of eider chicks after feeding metacercariae from the mantle of *M. edulis* and from the mantle of *G. gemma*.

Metacercariae have been found on the mantle of *M. arenaria* from Boothbay Harbor, Maine and Woods Hole, Massachusetts; on the mantle of *Hiatella arctica* and *Gemma gemma* from Boothbay Harbor; and on the mantle of *Mytilus edulis* from Newburyport, Massachusetts and Milford, Connecticut.

Sporocysts and cercariae from *M. arenaria* were described by Uzmann (1952). Further details are given in the present paper. Sporocysts and cercariae from *H. arctica* and from *G. gemma* are described in this report.

Laboratory-hatched eider ducks, recently hatched herring gulls, golden hamsters, and white mice have been used as possible experimental hosts. Adult and recently hatched herring gulls were provided by the Marine Biological Laboratory.

Experimental Results

Attempts to infect hamsters and white mice by feeding metacercariae from the three species of mollusks were not successful. Metacercariae from *Mya arenaria* and *Hiatella arctica*, although fed in large numbers, failed to infect eider ducks. As noted, metacercariae from *Mytilus edulis* and from *Gemma gemma* developed to sexual maturity in laboratory-raised and previously unexposed eider ducks. These worms were not only specifically distinct, but belong to different genera, as recounted in the descriptive section of the present paper.

[3] In a personal communication, Dr. John S. Rankin, Jr., reported that in 1938 he collected about one hundred gymnophallid trematodes from the ring-necked plover, *Charadrius semipalmatus*, which it is hoped may become available for study.

Figure 10. Metacercaria from *Hiatella arctica*, Boothbay Harbor, Maine. Specimen 0.21 mm. long, pressed to study the excretory system.

Figure 11. Metacercaria from *Gemma gemma*. Specimen 0.2 mm. long, same species as Figures 6 and 7.

Many worms were taken from the bursa Fabricii of eider ducks at Boothbay Harbor. Eggs of these parasites are embryonated when passed in the feces of their hosts, but do not hatch in sea-water. Accordingly, it is reasonably certain that the miracidia emerge only after the eggs reach the digestive tract of the first intermediate host. Eggs of worms, found as natural infections in the bursa Fabricii of eider ducks, were further embryonated and pipetted into the mantle cavities of *Mya arenaria* and *Mytilus edulis*. Other eggs were placed with specimens of *Hiatella arctica* in a gallon jar, half-filled with sea water and agitated by a stream of compressed air. The attempts to infect mollusks with eggs of the parasites were entirely fruitless. There is no assurance that the eggs were actually ingested although in natural infection it is probable that the eggs enter the mantle cavity with water currents, become enmeshed in the mucus that covers the gills, and reach the digestive tract in the stream of material that is driven by ciliary action from the gills to the mouth.

Metacercariae were removed from *M. arenaria*, *H. arctica*, and *G. gemma* and introduced into the mantle cavities of each of the other species. In no instance was successful transplantation assured. Even attempts to transfer metacercariae from one *M. arenaria* to another gave uncertain results. Often the worms failed to adhere to the new host. Also, the recipients may have been infected before the introduction of the new worms and a degree of resistance may have been developed. When experiments must be conducted on specimens that have been exposed previously to the same or related parasites, results must be subjected to rigid scrutiny.

Descriptive Results

Adult worms

I. From the bursa Fabricii of *Somateria mollissima* taken at Boothbay Harbor, Maine (Fig. 1)

About one hundred worms were collected; some were studied alive, others were fixed and stained for morphological study, and the others were dissected to obtain eggs for infection experiments. The worms are oval to pyriform, usually rounded anteriorly and more pointed posteriorly. When active the sides may be almost parallel and either end may be wider. They vary from 0.47 mm. long by 0.30 mm. wide to 1.00 mm. long by 0.50 mm. wide, the size of the somewhat flattened specimen shown in Figure 1. The cuticula is covered with scale-like spines, somewhat smaller posteriorly. The acetabulum is situated slightly behind the middle of the body and measures 0.10 to 0.14 mm. in diameter. The anterior portion of the body contains many gland-cells whose ducts open to the surface, chiefly around the oral sucker. The oral opening is subterminal, the sucker measures 0.13 to 0.18 mm. in diameter and the pharynx, which follows immediately, is 0.045 to 0.055 mm. in diameter. The esophagus varies much in length with the extension and retraction of the anterior portion of the body and measures 0.06 to 0.20 mm. in length. The ceca are relatively short and may, when the body is contracted, extend to the level of the acetabulum. The excretory vesicle is Y-shaped, with long arms which when filled may extend to the level of the pharynx. They follow the contour of the lateral edges of the body, but in living specimens the anterior ends may become widened, flattened, lobed or slightly bifid, and retraction of the vesicle along the lateral faces of the ceca may produce the lyre-shaped appearance figured in many species of *Gymnophallus*. The flame-cell pattern was not com-

pletely worked out, but insofar as could be determined, it is $2[(2+2+2)+(2+2+2)]$, identical with that in the metacercariae from *M. arenaria* and *H. arctica* (Figs. 8, 10).

The testes are oval, and vary much in size in different individuals. They measure 0.06 to 0.13 mm. by 0.04 to 0.10 mm.; are lateral, acetabular to completely postacetabular, almost opposite; the one on the ovarian side is usually slightly more posteriad. Sperm ducts arise at the anterior ends, pass forward medially and dorsally and join to form the seminal vesicle which lies dorsal and anterior to the acetabulum. From a dorsal or ventral view it may appear ovoid or pyriform, but in lateral aspect the bipartite character is clearly apparent. The vesicle is followed by a cylindrical duct, enclosed in large prostate cells, which extends posteriad and ventrad opening into the small genital atrium. The common genital pore is median, just in front of the acetabulum. The ovary is lateral, usually on the left side, at the acetabular level. It is about the size of a testis and may partially overlap the testis of that side or the two may be separated, the ovary its own diameter in front of the testis. The oviduct arises at the median posterior aspect of the ovary, passes mediad and backward where it expands into a fertilization space from which Laurer's canal passes to the dorsal surface of the body. Immediately following, it receives the short vitelline duct and expands into the ootype, enclosed in the cells of Mehlis' gland. There is no seminal receptacle; instead, the initial section of the uterus is expanded and filled with spermatozoa. The course of the uterus is not constant; some of the loops described later may not be present, and the extent is determined in part at least by the number of eggs in the body. Typically, from the ootype the uterus passes backward, forms a loop or series of coils and then crosses behind the acetabulum to the antovarian side of the body. It then makes a backward loop, sometimes almost to the posterior end of the body, then a loop or series of coils forward almost to the level of the pharynx, then backward where behind the ceca it crosses to the ovarian side and coils may pass forward to the level of the pharynx, then backward mediad of the ovary, and then forward to the genital pore. The vitelline follicles are at the sides and above the acetabulum, six to twelve indistinct lobes on each side; they may extend through the ovarian and testicular zones; ducts from each side meet behind the acetabulum to form a small receptacle from which the common duct leads to the oviduct. The eggs are operculate, oval, and measure 0.021 to 0.025 mm. by 0.015 to 0.018 mm. (average 0.023 by 0.016 mm.).

II. From the gall bladder of *S. mollissima* taken at Boothbay Harbor, Maine (Figs. 2, 3)

Two specimens were found in the gall bladder of one bird; the bladders of seven other ducks were negative. The worms were about the same size; extended they measured 1.72 mm. long and 0.60 mm. in width and contracted 1.00 mm long and 0.90 mm. in width. Although about twice as large as the worms from the bursa, these specimens were similar in shape and moved in a similar manner. However, as in most trematodes, the shape and relative position of structures are so pliable that an account based on a single specimen may be very misleading. Figures 2 and 3, made from the same specimen, show changes in shape when alive and moderately relaxed and when fixed under coverglass pressure with the anterior portion retracted and the posterior portion extended. Like the worms from the

bursa, the anterior portion of the body contains many glandular cells. The acetabulum measures 0.17 to 0.185 mm. in diameter. The oral sucker is 0.18 to 0.23 mm. in diameter; the diameter of the pharynx is about one-third that of the oral sucker. The bifurcation of the digestive tract is about midway between the suckers and the ceca extend to the acetabular level. The excretory vesicle is almost identical with that of the worms from the bursa.

The testes are oval, 0.15 to 0.19 mm. in diameter, typically postacetabular; the seminal vesicle is in part dorsal to the acetabulum and the prostatic portion curves ventrad and posterad in front of the acetabulum to open into the genital atrium. The opening to the exterior is immediately anterior to the aperture of the sucker and may appear below the front portion of the acetabulum. The ovary is about the same size as the testes, lateral, sinistral in both specimens, at the acetabular level or slightly posteriad. The relations of the oviduct, ootype, and associated structures are quite similar to those in the worms from the bursa. The course of the uterus is similar also, with coils that extend almost to the posterior end of the body and others to the region of the pharynx. Some of the coils that initially were more median in position were pushed laterally by pressure of the coverglass. The vitelline follicles are lateral and posterior to the acetabulum; they extend through the ovarian and part of the testicular zone, but are in large part postacetabular. The eggs are about the same size as those in the worms from the bursa and average 0.023 by 0.017 mm.

III. From the intestine of *S. mollissima*; experimental infection after feeding metacercariae from *Mytilus edulis*, Long Island Sound, New York (Figs. 4, 5)

As noted earlier, sexually immature worms were recovered from the intestine of a hamster, seven days after feeding metacercariae from *M. edulis*. The largest worm, shown in Figure 4, is not quite sexually mature but measures, fixed and stained, 0.43 mm. long and 0.235 mm. wide. Feeding experiments were carried out later with eider chicks hatched in the laboratory from eggs sent from Boothbay Harbor, Maine. Feeding began when the birds were one day old. After ten successive days of feeding metacercariae, a series of worms was taken from the intestine of one bird. One worm, which had just begun egg-production, with seven eggs in the initial part of the uterus, is only slightly larger than the one from the hamster. The largest specimens, which measure 0.57 to 0.72 mm. in length, are not completely gravid, although coils of the uterus extend posteriad about one-half the distance from the acetabulum to the end of the body and forward to the pharynx. The worm which was just attaining maturity is 0.44 mm. long and 0.25 mm. wide. The acetabulum is 0.08 mm. in diameter; the oral sucker 0.092 mm. in diameter, and the pharynx is 0.057 mm. wide and 0.045 mm. long. The seminal vesicle is 0.056 mm. in diameter; the right testis is 0.09 by 0.06 mm., the left testis 0.09 by 0.056 mm.; the ovary 0.080 by 0.074 mm., and the eggs 0.027 by 0.020 mm. One of the largest specimens, shown in Figure 5, somewhat flattened, is 0.72 mm. long and 0.36 mm. wide. The acetabulum is 0.096 mm. in diameter; the oral sucker is 0.12 mm. wide and 0.10 mm. long; the pharynx is 0.057 mm. wide and 0.050 mm. long. The seminal vesicle measures 0.090 by 0.062 mm.; the right testis is 0.126 by 0.078 mm.; the left testis is 0.12 by 0.080 mm.; the ovary is 0.12 by 0.083 mm.; and the eggs average 0.026 by 0.019 mm. It appears that the first eggs are slightly larger than those produced later.

IV. From the intestine of *S. mollissima*; experimental infection after feeding metacercariae from *Gemma gemma* taken at Boothbay Harbor, Maine (Figs. 6, 7)

Laboratory-raised specimens of *S. mollissima*, never exposed previously to infection, were fed metacercariae on alternate days from October 13 to October 23, 1957, a total of five feedings. More than 100 worms, most of them sexually mature, were recovered from the intestine. Gravid specimens measured 0.15 to 0.33 mm. in length and 0.09 to 0.16 mm. in width. Juvenile worms were only slightly smaller. The cuticula bears flat, scale-like spines. The acetabulum is 0.029 to 0.037 mm. in diameter, only about one-half the size of the oral sucker. It is situated slightly posterior to the middle of the body. The oral sucker is 0.057 to 0.080 mm. in diameter; the posterior half of the sucker contains many unicellular glands which in living worms appear as yellowish columns, and the sucker when compressed has lateral ear-like projections (Figs. 6, 7). The pharynx is 0.027 to 0.033 mm. in diameter, almost as large as the acetabulum. The esophagus is variable in length; the ceca may be entirely preacetabular or approach the level of the gonads. The excretory vesicle is V-shaped with long arms which when filled may extend to the level of the pharynx. The flame-cell pattern could not be resolved since the worms were so filled with eggs that they recalled the figure of *Gymnophallus ovoplenus* as given by Jameson and Nicoll (1913). However, since the worms are almost fully grown in the metacercarial stage (Fig. 11), it is reasonably certain that the excretory system does not undergo change with reproductive maturity and the production of eggs. The testes are oval, 0.025 to 0.035 mm. by 0.035 to 0.050 mm. in diameter, situated on opposite sides in the posterior one-third to one-fourth of the body. Sperm ducts lead forward and mediad to open into a large, clavate seminal vesicle which extends from a level only slightly anterior to the testes almost to the bifurcation of the digestive tract. Anteriorly it becomes continuous with an ejaculatory duct, surrounded by secretory cells, which opens into the shallow genital atrium. The genital pore is median, some distance anterior to the acetabulum, often below the posterior edge of the pharynx. The ovary is lateral, either left or right, slightly smaller and immediately anterior to or overlapping the testis of the ovarian side. The oviduct arises at the median, posterior portion of the ovary, passing mediad where it enters the ootype. A seminal receptacle and Laurer's canal were not observed, but may be present. The vitellaria are composed of compact follicles, forming reniform glands, dorsal, lateral and somewhat posterior to the acetabulum. Vitelline ducts pass mediad and form a common duct which opens into the initial portion of the ootype. Mehlis' gland is present but consists of a small number of cells. The coils of the uterus may almost fill the body from the level of the oral sucker to the posterior end. The eggs measure 0.015 to 0.017 by 0.010 to 0.011 mm.

Metacercariae

I. From *Mya arenaria*, taken at Boothbay Harbor, Maine and at Woods Hole, Massachusetts (Fig. 8). Uniformly light infection, 1–12 worms per clam; about 25% of the clams infected

Specimens vary greatly in size as the unencysted metacercarial stage is an important growth phase in the life of the species. The worms actively ingest material

from the mantle of the host and develop from a size hardly larger than a cercaria (0.12 to 0.25 mm. in length when retracted and extended) to almost definitive size (0.60 to 1.20 mm., corresponding measurements of length). Ordinarily the width is about one-half the length, but specimens may contract until the length and width are equal or elongate until the width is less than one-fourth the length. During the metacercarial period the larvae increase about five times in length and the organs, except the gonads and reproductive structures, attain almost full growth. There are six papillae around the acetabular opening. The acetabulum measures 0.13 to 0.14 mm. in diameter in the large individuals. The cuticular spines are pointed and sharp. The anterior end bears several small papillae, each tipped by a short, stiff bristle. The anterior region of the body contains a large number of unicellular glands which open around the oral sucker. The oral sucker is 0.147 to 0.16 mm. in diameter in large specimens. The digestive ceca are lined with large cells and yellow granules are conspicuous in the cytoplasm of the cells and in the lumen of the ceca. The yellow material appears like that in the digestive gland of the clam and may be taken by the parasite from the vascular fluid of the mollusk. The excretory system has been worked out and the arrangement of the tubules and flame-cells is shown in Figure 8. The formula is $2\,[(2+2+2)+(2+2+2)]$; the common duct, which leads from the junction of the anterior and posterior collecting ducts, bears tufts of cilia which may simulate flame cells.

II. From *Mytilus edulis*, taken at Milford, Connecticut and Newburyport, Massachusetts (Fig. 9). Uniformly light infection, 1–10 worms per mussel; about 20% of the mollusks infected

The metacercariae in *M. edulis* produce lesions in the mantle and body-wall, which may result in the deposition of nacreous material. The larvae attain a length of 0.4 to 0.6 mm. and a width of 0.2 to 0.3 mm. In a fixed and stained specimen, 0.45 mm. long and 0.275 mm. wide, the acetabulum is 0.078 by 0.07 mm.; the oral sucker is 0.088 mm. and the pharynx is 0.030 mm. in diameter. Metacercariae from *M. edulis* developed to sexual maturity in a ten-day-old eider duck (*cf.* Figs. 4, 5).

III. From the mantle of *Hiatella arctica*, taken at Boothbay Harbor, Maine (Fig. 10). Uniformly light infection, 10 to 8 worms per clam; about 20% of mollusks infected

The metacercariae in *H. arctica* are similar in shape to those in *Mya arenaria*; the smallest individuals of the two species are about the same size, 0.12 to 0.175 mm. in length, but the largest worms from *H. arctica* do not exceed 0.3 mm. in length and accordingly are only about one-fourth as large as those from *M. arenaria*. The suckers, however, are relatively larger; the acetabulum measures 0.050 to 0.058 mm. in diameter in large specimens. The anterior end of the body does not contain the large number of glandular cells so characteristic of the worms from *M. arenaria* and the digestive ceca do not contain the yellow material so conspicuous in that species. The oral sucker of large individuals measures 0.054 to 0.064 mm. in diameter. Some of the measurements were made while the worms were under considerable pressure from the coverglass while the details of the excretory system

were studied. The excretory system is identical with that in the larva from *M. arenaria* and the flame-cell formula is $2\,[(2+2+2)+(2+2+2)]$.

IV. From the mantle of *Gemma gemma* at Boothbay Harbor, Maine (Fig. 11). Uniformly light infection; 1 to 10 worms per clam; about 10% of the clams infected

These metacercariae were fed to an eider duck and became mature (*cf.* Figs. 6, 7). Specimens from *G. gemma* measure 0.13 to 0.23 mm. in length and 0.06 to 0.12 mm. in width. The anterior end contains many glandular cells that open around the oral sucker. The cuticula bears flat, scale-like spines. The acetabulum is just posterior to the middle of the body and is 0.028 to 0.033 mm. in diameter. The oral sucker measures 0.05 to 0.07 mm. in diameter in large individuals. The posterior half of the sucker contains yellowish columns as described for the adult and when compressed, the sucker has lateral ear-like projections. The pharynx is 0.026 to 0.030 mm. in diameter and the ceca usually extend into the postacetabular zone and often to the gonads. The reproductive structures are well developed. The testes, ovary and vitelline glands are almost as large as in the sexually mature individuals and the terminal portions of the ejaculatory duct and metraterm are shown in Figure 11. The excretory vesicle is typical of the gymnophallids but the flame-cell pattern is simpler; it is shown in Figure 11 and the formula is $2\,[(2+2)+(2)]$. Such a difference probably has considerable taxonomic significance.

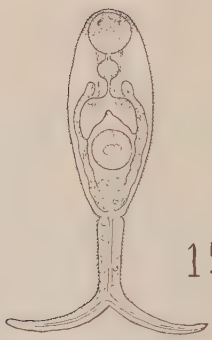
Sporocysts and cercariae

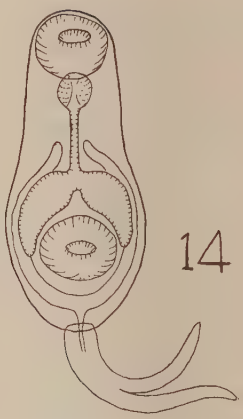
I. From *Mya arenaria* taken at Newburyport, Massachusetts and Boothbay Harbor, Maine (Fig. 12)

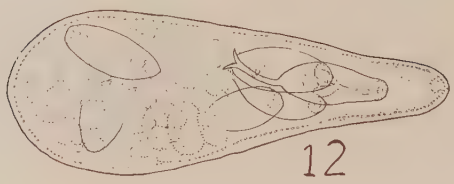
This species, described by Uzmann (1952) from *M. arenaria* taken at Newburyport, Massachusetts, has been found in the same host-species from Boothbay Harbor, Maine. The incidence of infection is low also in Maine; only three infections have been observed in the dissection of over 1000 clams. No cercariae were found in water in which the clams were kept, perhaps because the larvae were carried away in the current of water flowing over the mollusks. The cercariae were described and figured by Uzmann who noted that a similar and probably identical larva had been described by Stafford (1912). Uzmann also noted the close morphological agreement between the cercaria from *M. arenaria* and *Cercaria discursata* Sinitsin, 1911. Allison (1943) assigned *Leucochloridiomorpha constantiae* (Mueller, 1935), which has a furcocercous cercaria, to the family Brachylaemidae and suggested that *C. discursata* may belong to the same family. It now appears that the resemblance between the cercaria of *L. constantiae* and *Cercaria discursata* is merely superficial and that both *C. discursata* and *C. myae* should be placed in the subfamily Gymnophallinae.

II. From *Hiatella arctica* taken at Boothbay Harbor, Maine (Figs. 13, 14)

The description of this species is based entirely on material collected by Uzmann in 1953. Of 13 specimens examined on March 18th, 2 were infected; of 136 ex-







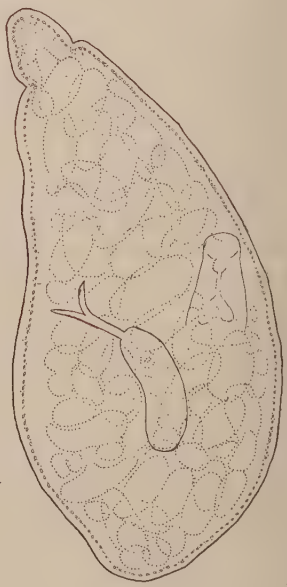


PLATE III

FIGURE 12. Sporocyst, 0.67 mm. long, and cercariae from *Mya arenaria*. This is *Cercaria myae* Uzmann, 1952.

FIGURE 13. Sporocyst, 0.80 mm. long, and cercariae from *Hiatella arctica*. This species is identified as *Cercaria reesi* Hutton, 1953.

amined May 12th, 6 were infected. Several hundred specimens of *H. arctica*, taken from the same area where Uzmann made his collections, have been examined in the summers of 1956 and 1957 without finding the parasite.

The sporocysts are oval to pyriform, usually with a neck-like extension which may be one-fourth or even one-third of the total length of the sporocyst and which bears the birth-pore at the end. The largest fixed and stained sporocyst is 0.96 mm. long and 0.37 mm. wide, but most of them are much smaller. The one shown in Figure 13 is 0.8 mm. long. The cercariae have forked tails, spined cuticula and no eye-spots; the body is 0.12 to 0.175 mm. in length and 0.05 to 0.068 mm. wide. The acetabulum is 0.036 to 0.043 mm. in diameter and the oral sucker is approximately the same size. The tail-stem is variable in length, 0.02 to 0.052 mm., and the furci are somewhat longer when fully extended, but they may contract to less than one-half the fully extended length. The pharynx is 0.015 to 0.022 mm. in diameter, spherical to oval, and longer than broad when the anterior end is protruded. The cephalic glands and ducts could not be resolved with certainty. The excretory vesicle is shown in Figure 14, but since the supply of living material was limited, the flame-cell formula was not worked out.

III. From *Gemma gemma*, taken at Boothbay Harbor, Maine (Figs. 15, 16)

No infection by this species was discovered by isolation of the clams, perhaps because the larvae swim well and were carried away in the running water that bathed the mollusks. Of 824 *G. gemma* dissected, three were infected. The sporocysts were dispersed in the interlobular spaces of the digestive gland. They are cylindrical to oval to pyriform to clavate, with a narrow end in which the birth-pore is situated. The smaller ones are motile while the larger ones lose motility as they become filled with cercariae. They may extend to a length of about 0.50 mm. The cercariae emerge from the clam and swim vigorously. In swimming, the tail is turned ventrad, the furci are extended and lash from side to side while the anterior end wobbles back and forth. Otherwise, the tail manifests nervous twitching movements while the furci separate and then come together. When killed by adding hot A F A (alcohol-formol-acetic acid) solution to a beaker containing a small amount of swirling sea-water in which they are suspended, the cercariae are very uniform in size and shape (Fig. 15). The cuticula bears spines on both the body and tail. The body is 0.12 to 0.14 mm. in length and 0.04 to 0.05 mm. in width. The tail-stem is 0.04 to 0.05 mm. in length, 0.015 to 0.017 mm. wide at the base and 0.013 to 0.015 mm. wide at the bifurcation of the tail. The furci are 0.060 to 0.068 mm. long and 0.011 mm. wide at the base. Alive, the cercarial body varies from 0.08 to 0.2 mm. in length and 0.03 to 0.07 mm. in width; the tail varies from 0.05 to 0.14 mm. in length, the stem from 0.025 to 0.06 mm. and the furci from 0.025 to 0.13 mm. There are no eye-spots. The acetabulum, situated just posterior to the middle of the body protrudes slightly and measures 0.027 to 0.030 mm. in diameter. The oral sucker is the same size as the acetabulum; there is a short prepharynx, and the pharynx measures 0.014 to 0.019 mm. in

FIGURE 14. *Cercaria reesi* Hutton, 1953 from *Hiatella arctica*, Boothbay Harbor, Maine.
FIGURE 15. Cercaria from *Gemma gemma*, Boothbay Harbor, Maine.
FIGURE 16. Cross-section of *G. gemma* through the pedal ganglion, mantle and part of the gill of one side removed, to show location and extent of the infection. At this level, the sporocysts are more numerous than the follicles of the digestive gland.

diameter. The esophagus varies in length as the body elongates and contracts; in fixed specimens it is about as long as the diameter of the pharynx. The ceca are ovate, wider anteriorly. They may be entirely preacetabular or extend posteriad to the level of the middle of the acetabulum; their walls are composed of large cells. A pair of lobed unicellular glands is situated, one on either side, at the level of the intestinal bifurcation and their ducts pass forward to open above the mouth. The excretory vesicle consists of a dorsal, pouch-like expansion from which, on the ventral side, the arms extend forward to the pharyngeal level. They are ventral to the digestive ceca and are filled with concretions, 0.005 to 0.006 mm. in diameter. On each side there is a flame-cell at the level of the pharynx, and the capillary from it divides at the level of the intestinal bifurcation; one branch leads to the vesicle but the other could not be followed with certainty. It may extend back to a flame-cell located at the level of the vesicular pouch, but the duct from that cell was hidden at the acetabular level by concretions in the excretory vesicle.

Discussion

The present account includes descriptions of sporocysts, cercariae, and metacercariae from marine bivalves and adult worms from the eider duck, *Somateria mollissima*. Specific identification is so uncertain that we prefer to list the worms by host and location rather than propose names that might further confuse the taxonomic situation.

The adult forms I, II, and III are members of the genus *Gymnophallus*. Worms from the bursa Fabricii of *S. mollissima*, Adult No. I, although they are somewhat smaller, may be identical with *G. bursicola* Odhner, 1900 or *G. dapsilis* Nicoll, 1907, if indeed these species are actually distinct. It is interesting to note that Jameson and Nicoll (1913) reported *G. dapsilis* from the intestine as well as the bursa. Our Adult No. II, from the gall bladder, may be identical with *G. deliciosus* (Olsson, 1893) or *G. choledochus* Odhner, 1900, if the latter of these species is really valid. The account of Isaitchikow (1924), if it dealt with a single species and if that species was *G. choledochus*, would suggest that the reported differences between *G. choledochus* and *G. deliciosus* are not significant. The single specimen from the gall bladder of *S. mollissima* taken in Iceland and described as a new species, *G. bilis*, by Brinkmann (1956) is similar to *G. bursicola* and, despite reported differences, may belong to that species. The naming of a new species on a single specimen is not recommended. Our Adult No. III, from the intestine of an eider chick, the sexually mature stage of the metacercaria in *Mytilus edulis*, is larger than *G. somateriae* (Levinsen, 1881) and may be *G. bussicola*, which had not yet settled in the bursa and reached full size.

Our Adult No. IV is clearly a member of the genus *Parvatrema* Cable, 1953. The worms are very similar to *Parvatrema borinqueñae* Cable, 1953, the morphological differences are minor, the chief differences are in geographical location and in primary and secondary hosts. The cercariae from *Gemma purpurea*, described by Cable as larvae of *P. borinqueñae*, are smaller, the tail is relatively much smaller and the cercaria, according to Cable, "is a poor swimmer" when compared with the cercariae from *Gemma gemma* at Boothbay Harbor, Maine. Because of these differences, we recognize the worms we have described as a new and distinct species for which we propose the name *Parvatrema borealis*.[4] Cable noted the possible

identity of *Parvatrema* and *Gymnophalloides*. Both Yamaguti (1939) and Cable (1953) accredit this genus to Fujita (1925) although it appears from the footnotes in his French translation of the text and from his accompanying note, that Dollfus claims credit for the generic name. The worms described as *Gymnophallus ovoplenus* by Jameson and Nicoll (1913) differ distinctly from *Gymnophallus* and although the morphology is very imperfectly known, it appears from the figure and account of Jameson and Nicoll that the worms agree better with the characteristics of *Parvatrema* and accordingly we transfer the species to the latter genus as *Parvatrema ovoplenus* (Jameson and Nicoll, 1913).

Metacercaria I is common in *Mya arenaria* but it did not persist or develop in mice, hamsters, eider ducks or herring gulls, and other stages in the life-cycle are yet unknown. Only when the cercarial and adult stages become available will the taxonomic position of the species be clarified.

Metacercaria II is common in *Mytilus edulis*; it developed in the eider chick and as noted, may be the asexual stage of *G. bursicola*.

Metacercaria III is relatively common in *Hiatella arctica* but like Metacercaria I, it did not persist or develop in experimental animals and its status is yet uncertain.

Metacercaria IV, from *Gemma gemma*, is the asexual stage of *Parvatrema borealis* n. sp., which developed in large numbers in the intestine of *S. mollissima*. Whether other birds also serve as final hosts is unknown but probable.

The sporocysts and Cercaria I, which may cause the condition known by clam diggers as "waterbelly," were described by Uzmann (1952). Although the species has received further study, later stages in the life-cycle of the parasite are still unresolved.

The sporocysts and Cercaria II, from *Hiatella arctica* at Boothbay Harbor, agree in detail with the corresponding stages of *Cercaria reesi* as described by Hutton (1953) from *H. arctica* and *Hiatella striata* at Plymouth, England. They are referred to that species.

The sporocysts and cercariae III, from *G. gemma* at Boothbay Harbor may be identical with the metacercariae from the same host-species which developed to maturity in *S. mollissima* and which we describe as *Parvatrema borealis* n. sp. If so, the oral sucker must double in diameter while the acetabulum remains essentially unchanged.

Present literature concerning gymnophalline trematodes discloses descriptions of twelve species of adult worms from the gall bladder, intestine, ceca and bursa Fabricii of various shore-birds; an even larger number of metacercariae from marine mollusks; and a score of different sporocysts and cercariae have been recorded from various marine bivalves. Yet there is no agreement on the number of valid species and specific relations between particular cercariae, metacercariae and sexually mature worms remain undetermined. As yet there are no precise data concerning host specificity, *i.e.*, the ability of one species to infect different primary, secondary, and definitive hosts. Furthermore, information concerning organ specificity is equally meager, and it is uncertain whether or not members of a given species can persist in more than one location in or on a given host. Comparison of specimens from different hosts and different locations does not provide satisfactory answers;

[4] Holotype and paratype deposited in U. S. Nat. Mus., Helminth. Coll. No. 56235.

the selected site in each instance may be determined by physiological adjustments. The extent of morphological variation that may result from development in different hosts or different locations is quite unknown. Only when life-cycles have been discovered and controlled experiments permit tests on host and organ specificity, will it be possible to determine the extent of variation in individual species and the validity of the several named adult and larval forms.

LITERATURE CITED

Allison, L. N., 1943. *Leucochloridiomorpha constantiae* (Mueller) (Brachylaemidae), its life cycle and taxonomic relationships among digenetic trematodes. *Trans. Amer. Micros. Soc.*, **62**: 127–168.

Atkins, Daphne, 1931. On abnormal conditions of the gills in *Mytilus edulis*. Part II. Structural abnormalities, with a note on the method of division of the mantle cavity in normal individuals. *J. Mar. Biol. Assoc., N. S.*, **17**: 489–543.

Brinkmann, A., Jr., 1956. Trematoda, *in* the Zoology of Iceland, 2(11): 1-34.

Cable, Raymond M., 1953. The life-cycle of *Parvatrema borinqueñae* gen. et sp. nov. (Trematoda:Digenea) and the systematic position of the Gymnophallinae. *J. Parasit.*, **39**: 408–421.

Cole, H. A., 1935. On some larval trematode parasites of the mussel (*Mytilus edulis*) and the cockle (*Cardium edule*). *Parasitol.*, **27**: 276-280.

Cole, H. A., 1938. On some larval trematode parasites of the mussel (*Mytilus edulis*) and the cockle (*Cardium edule*). Part II. A new larval *Gymnophallus* (*Cercaria cambrensis*) sp. nov. from the cockle (*Cardium edule*). *Parasitol.*, **30**: 40-43.

Dawes, Ben, 1946. The Trematoda. Cambridge University Press.

Dollfus, R. P., 1923. Le trématode des perles de nacre des moules de Provence. *C. R. Acad. Sci., Paris*, **176**: 1427–1429.

Dubois, Raphael, 1901. Sur le mécanisme de la formation des perles fines dans le *Mytilus edulis*. *C. R. Acad. Sci., Paris*, **133**: 603-605.

Dubois, G., J. G. Baer and L. Euzet, 1952. Une nouvelle cercaire du plancton marin de Sète, *Cercaria mathiasi*. *Rev. Suisse de Zool.*, **59**: 503-510.

Fuhrmann, O., 1928. Trematoda, in Kükenthal und Krumbach, Handbuch der Zoologie, 2(2): 1–140.

Fujita, Tsunenobu, 1925. Études sur les parasites de l'huitre comestible du Japon *Ostrea gigas* Thunberg. Traduction accompagnée de notes, de diagnoses et d'une bibliographie par Robert-Ph. Dollfus. *Ann. Parasit.*, **3**: 37–59.

Garner, Robert, 1872. On the formation of British pearls and their possible improvement. *J. Linn. Soc., London, Zool.*, **11**: 426-428.

Giard, A., 1897. Sur un distome (*Brachycoelium* sp.), parasite des pélécypodes. *C. R. Soc. Biol., Paris, (10 sér., 4)* **49**: 956-957.

Giard, A., 1903. Sur la production volontaire des perles fine, ou margarose artificielle. *C. R. Soc. Biol., Paris*, **55**: 1225-1226.

Giard, A., 1907. Sur les trématodes margaritigenes du Pas-de-Calais (*Gymnophallus somateriae* Levinsen et *G. bursicola* Odhner). *C. R. Soc. Biol., Paris*, **63**: 416–420.

Glude, J. B., 1955. The effects of temperature and predators on the abundance of the soft-shell clam (*Mya arenaria*) in New England. *Trans. Amer. Fish Soc.* **84**: 13–26.

d'Hamonville, Baron, 1894. Les moules perlieres de Billiers. *Bull. Soc. Zool. France*, **19**: 140 142.

Huet, L., 1888. Note sur un parasite nouveau du *Cardium edule*. *Bull. Soc. Linn. Normandie, 4 sér.*, **2**: 149-152.

Hutton, Robert F., 1952. Studies on the parasites of *Cardium edule* L.: *Cercaria fulbrighti* n. sp., a *Gymnophallus* larva with a forked tail. *J. Mar. Biol. Assoc.*, **31**: 317-326.

Hutton, Robert F., 1953. *Cercaria reesi* n. sp., a new furcocercous larva from Plymouth. *J. Mar. Biol. Assoc.*, **31**: 581–585.

Isaitchikow, I. M., 1924. Des variations individuelles chez *Gymnophallus choledochus* (Odhner, 1900). *C. R. Soc. Biol., Paris*, **91**: 1187–1189.

JAMESON, H. L., 1902. On the origin of pearls. *Proc. Zool. Soc., London*, **1**: 140–166.

JAMESON, H. L., AND WILLIAM NICOLL, 1913. On some parasites of the scoter duck (*Oedemia nigra*), and their relation to the pearl-inducing trematode in the edible mussel (*Mytilus edulis*). *Proc. Zool. Soc. London*, pp. 53–63.

JOHNSTONE, JAMES, 1905. Internal parasites and diseased conditions of fishes. *Proc. Trans., Liverpool Biol. Soc.*, **19**: 278–300.

VON LA VALETTE ST. GEORGE, A. J. H., 1855. Symbolae ad trematodum evolutionis historiam. Diss. 38 pp. Berolini.

LEBOUR, MARIE V., 1904. A preliminary note on a trematode parasite in *Cardium edule*. Rep. Scient. Invest. Northumberland Sea Fish. Comm., pp. 82–84.

LEBOUR, MARIE V., 1905. Notes on Northumberland trematodes. Rep. Scient. Invest. Northumberland Sea Fish. Comm., pp. 100–105.

LEBOUR, MARIE V., 1908. Trematodes of the Northumberland coast, No. II. *Trans. Nat. Hist. Soc. Northumberland, Durham and Newcastle, n.s.*, **2**: 7–9, 13–14.

LEBOUR, MARIE V., 1912. A review of the British marine cercariae. *Parasitol.*, **4**: 416–456.

LEVINSEN, G. M. R., 1881. Bidrag til Kundskab om Grønlands Trematodfauna. Overs. K. Danske Vidensk. Selsk. Forh. Kjøbenh. (1): 52–84.

MARKOWSKI, S., 1936. Ueber die Trematodenfauna der baltischen Mollusken aus der Umgebung der Halbinsel Hel. *Bull. Internat. Acad. Polon. Sc. et Lett., Cl. Sci., Math. et Nat. Sci., B*, **II**: 285–317.

MÖBIUS, K., 1857. Die echten Perlen. Abhandl. Geb. Nat. naturw. Verein, Hamburg, 4(1).

NICOLL, WILLIAM, 1906. Notes on the trematode parasites of the cockle (*Cardium edule*) and mussel (*Mytilus edulis*). *Ann. Mag. Nat. Hist., ser. 7*, **17**: 148–155.

NICOLL, WILLIAM, 1907. Observations on the trematode parasites of British birds. *Ann. Mag. Nat. Hist., ser. 7*, **20**: 245–271.

ODHNER, T., 1900. *Gymnophallus*, eine neue Gattung von Vogeldistomen. *Centralb. Bakt., Abt. I*, **28**: 12–23.

ODHNER, T., 1905. Die Trematoden des arktischen Gebietes. *In:* Römer u. Schaudinn, Fauna Arctica, 4 (2): 291–372.

ODHNER, T., 1911a. Zum natürlichen System der digenen Trematoden. III. *Zool. Anz.*, **38**: 97–117.

ODHNER, T., 1911b. Zum natürlichen System der digenen Trematoden. IV. *Zool. Anz.*, **38**: 513–531.

OGATA, T., 1944. On the morphology, ecology and life history of an agamodistome parasite in a bivalve, *Paphia* (*Ruditapes*) *philippinarum* (Adams and Reeve). *Sci. Rep. Tokyo Bun Daig., 7B*, **102**: 1–24.

PALOMBI, A., 1924. Le cercarie del genere *Gymnophallus* Odhner dei Mitili. *Pubb. Staz. Zool. Napoli*, **5**: 137–152.

PALOMBI, A., 1934. Gli stadi larvali dei Trematodi del Golfo di Napoli. 1. Contributo allo studio della morphologia, biologia e systematica delle cercariae marine. *Pubb. Staz. Zool. Napoli*, **14**: 51–94.

PELSENEER, P., 1906. Trématodes parasites de mollusques marins. *Bull. Sci. France et Belg.*, **40**: 161–186.

REES, GWENDOLEN, 1939. *Cercaria strigata* Lebour from *Cardium edule* and *Tellina tenuis*. *Parasitol.*, **31**: 458–463.

VON SIEBOLD, C., 1837. Fernere Beobachtungen über die Spermatozoen der wirbellosen Thiere. Müller's Arch. Anat. Physiol. wiss. Med., 381–439.

SINITSIN, D. F., 1911. The parthenogenetic generation of the trematodes and their descendents in the Black Sea mollusks. (Russian text) Mem. Acad. Imp. Sci., St. Petersb., Cl. Phys. Math., 8 ser. 30 (5): 127 pp.

SMITH, O. R., 1950. Observations on soft clam mortalities in Massachusetts. Convention Addresses, Proc. Natl. Shellfish Assn. 31–33.

SMITH, O. R., AND E. CHIN, 1951. The effects of predation on soft clams, *Mya arenaria*. Convention Addresses Natl. Shellfish Assn. 37–44.

STAFFORD, J., 1912. On the fauna of the Atlantic coast of Canada. Third report—Gaspé, 1905–1906. Contrib. Canad. Biol., 1906–1912: 45–67.

STOSSICH, M., 1899. Los membramento dei *Brachycoelium*. *Boll. Soc. Adriat. sc. nat. Trieste*, **19**: 7–10.

STUNKARD, HORACE W., 1957. The morphology and life-history of the digenetic trematode, *Microphallus similis* (Jägerskiöld, 1900) Baer, 1943. *Biol. Bull.*, **112**: 254–266.

UZMANN, JOSEPH R., 1952. *Cercaria myae* sp. nov., a fork-tailed larva from the marine bivalve, *Mya arenaria*. *J. Parasit.*, **38**: 161–164.

UZMANN, JOSEPH R., 1953. *Cercaria milfordensis* nov. sp., a microcercous trematode larva from the marine bivalve, *Mytilus edulis* L. with special reference to its effect on the host. *J. Parasit.*, **39**: 445–451.

VILLOT, F. C. A., 1875. Recherches sur les helminthes libres ou parasites des côtes de la Bretagne. *Arch. zool. expér. gén.*, **4**: 451–482.

VILLOT, F. C. A., 1878. Organization et développement de quelques espèces de trématodes endoparasites marins. *Ann. Sci. Nat. Zool.*, **49**: (art. 2), 40 pp.

YAMAGUTI, S., 1939. Studies on the helminth fauna of Japan. Part 25. Trematodes of birds. IV. *Jap. J. Zool., Tokyo*, **8**: 129–210.

YOUNG, R. T., 1936. A fork-tailed cercaria from Bering Sea, with a note on the marine furcocercous cercariae hitherto described. *J. Parasit.*, **22**: 255–258.

A METHOD OF DETERMING THE SEX OF THE STRIPED BASS, *ROCCUS SAXATILIS* (WALBAUM)

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Abstract

A method is described for sexing striped bass *Roccus saxatilis* (Walbaum) by use of a serrated-jaw ear forceps. The instrument is used to extract gonads from dead fish in samples of commercial catches, without incurring damage to the fish which affects the market quality. The gonads are examined later in the laboratory and are identified as male or female. The technique has proven satisfactory in large scale sampling of commercial catches.

Introduction

In a recent study of striped bass *Roccus saxatilis* (Walbaum) undertaken by the United States Fish and Wildlife Service, it became necessary to determine the sex ratio in North Carolina populations for adequate interpretation of data on population dynamics, fish movement, and spawning activity.

Raney (1952) and Merriman (1941) state that no valid way has been found to determine the sex of striped bass by the use of external characters and that the gonads must be inspected if differentiation is to be made. Workers in the past have sexed dead striped bass by examining their reproductive organs. Gonads were obtained by dressing fish for sportsmen, from fish being dressed in commercial fish houses (Merriman, 1941; and Morgan and Gerlach, 1950), and by purchasing fish especially for sex-ratio studies or for studies concerning reproductive cycles (Vladykov and Wallace, 1952). The sex of ripe fish, living or dead, can be readily determined since reproductive products are exuded upon application of digital pressure in the region of the genital pore. However, samples are rarely taken from a population, even on the spawning ground, in which all fish are fully ripe. Consequently a method of internal sexing is required even here.

Vladykov and Wallace (1952) found that the numerical relationship of males to females does not remain static through all seasons of the year. Therefore, a complete picture of the relationship of the sexes of striped bass requires sampling throughout the year in all regions occupied by a given population.

It is a common practice in North Carolina as in other states for striped bass to be marketed as whole fish. An internal sexing method was devised which is accurate and does not reduce the market value of the fish.

The author wishes to express his appreciation to the following: Messrs. William S. Davis and Robert D. Lewis who shared in the development of the technique; to the striped bass investigations staff of the U.S. Fishery Laboratory, Beaufort, North Carolina, for assistance in field testing and perfecting the method; and to fish dealers of the Albemarle Sound region of North Carolina, who cooperated so generously in supplying fish for our studies.

Method of Sexing

After experimentation with several types of surgical instruments it was found that gonadal tissue could be extracted through the vent by use of ear forceps having serrated jaws.[1]

A thin blade knife or a scalpel is inserted in the vent and a slit is made through the dorsal wall of the intestine (Fig. 1). The closed forceps are then passed through the incision, opened, moved forward, and closed to grasp the gonad.

Once the gonad is grasped, a firm, constant pull is exerted on the forceps with one hand while the other hand is used to make short, lateral movements of the fish to break the membranes surrounding the gonads. At times a portion of the gonad is torn away and at other times, particularly in small fish, an entire testis or ovary is pulled free. The vent is not noticeably enlarged even after the removal of an entire, relatively large gonad. A fragment of gonadal material large enough to be identified as such in the field is sufficiently large for laboratory identification as to sex. Practice is required in locating gonads with the forceps, and in separating gonadal material from adipose and intestinal tissue which are also frequently withdrawn from the body cavity. It has been noted that fewest mistakes are made and greater speed is achieved when work is done with relatively small (9 to 15 inch) striped bass. Frequently tissue can be extracted with greater facility from fish over 20 inches in length by inserting the instrument directly into the genital pore, grasping the gonadal tissue, and extracting the material through the same opening. This is impractical in smaller fish because of the size of the genital pore which prohibits insertion of the instrument without mutilation of the fish. Thus far, forceps have not been used to sample gonads which are in other than the resting stage.

After extraction, each gonad or fragment thereof has been placed in a 4 milliliter vial containing 5 percent formalin and a coded label. Code numbers corresponding to those on scale envelopes upon which length, weight, date and location of capture, gear employed, and other pertinent data are recorded.

Later the sex of the tissue is determined in the laboratory by means of a binocular dissecting microscope. Identification in this manner presents no

[1]The instrument was supplied by the American Hospital Supply Corporation, Atlanta Division, Chamblee, Georgia, and is cataloged as Hartman Ear Forceps, serrated jaw, item No. 330-25.

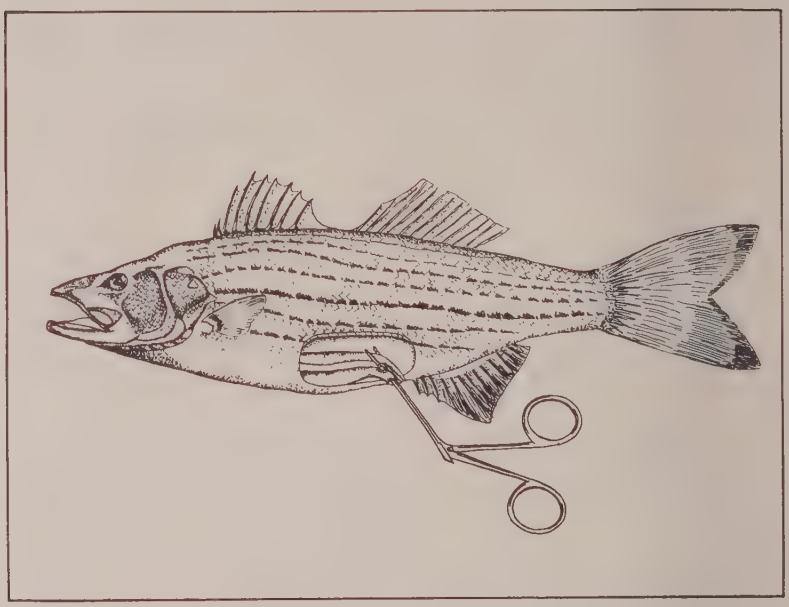

FIGURE 1.—Use of ear forceps in sexing striped bass. Forceps are inserted in vent and through intestinal wall to grasp gonad.

difficulty since the granular oocytes in ovarian tissue are readily distinguishable from the fine-textured spermatocytes.

Field examination of striped bass gonads showed that the tissue from testes is usually pale or whitish in appearance and that ovarian tissue is usually reddish and somewhat translucent. A sample of gonads was tentatively identified as male and female on the basis of appearance when sampled. Re-examination of this material in the laboratory showed that microspcopic examination of the gonads is necessary for 100 percent accuracy in distinguishing sexes from resting gonads.

The rapidity of sexing by this method varies considerably, depending upon the experience of the operator, the conditions under which he is working, and the size of the fish. One operator and a recording assistant sexed 125 striped bass in approximately three hours. In addition they took scales and measurements and recorded these data.

It is possible that this method may be applied to other species of fish in which determination of sex by external inspection is difficult or impossible and in which sex ratio studies are prerequisite to the solution of research problems.

Literature Cited

Merriman, Daniel
1941. Studies on the striped bass *(Roccus saxatilis)* of the Atlantic Coast. Bull. 35, U. S. Fish and Wildlife Service, Vol. 50 pp. 1-77.

Morgan, Alfred R., and Arthur R. Gerlach
1950. Striped bass studies on Coos River, Oregon, in 1949 and 1950. Oregon Fish Commission. Contribution No. 14, pp. 1-31.

Raney, Edward C.
1952. The life history of the striped bass, *Roccus saxatilis* (Walbaum). Bulletin of the Bingham Oceanographic Collection, Vol. XIV, Article 1, pp. 5-97.

Vladykov, Vadium D., and David H. Wallace
1952. Studies of the striped bass, *Roccus saxatilis* (Walbaum), with special reference to the Chesapeake Bay region during 1936-1938. Bulletin of the Bingham Oceanographic Collection, Vol. XIV, Article 4, pp. 132-177.

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PROBLEMS RELATIVE TO THE ATLANTIC COAST STRIPED BASS FISHERY AND STATUS OF ITS BIOLOGICAL RESEARCH

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The Atlantic Coast distribution of striped bass, *Roccus saxatilis* (Walbaum), ranges from the St. Lawrence River in Canada to the St. Johns River in Florida, and in the Gulf of Mexico from western Florida to Louisiana. In 1955, the year of most recent available catch data, 5,000,000 pounds of striped bass valued at over one million dollars were taken commercially. In its range south of North Carolina, both sport and commercial catches are relatively small as compared to those of the middle and north Atlantic States. Throughout the range, records of sport catches are virtually non-existent, but they are known to be large. The striped bass fishery ranks high economically with the fisheries of other commercially exploited species, and its status as a sport fishery is increasing each year.

Because of its importance to the two fishing interests, an examination is made in this report of the more outstanding problems which are now confronting the striped bass fishery, the progress in research which has been and is being made, and the manner in which future research should be designed toward establishing management criteria.

Problems in Need of Solution

The most comprehensive problem now facing biologists engaged in striped bass research is that of advancing to a point where legislative bodies may be guided wisely in arbitrating such issues as that now existing between sport and commercial groups in the capture of striped bass. The legislative leaders should be able to rely upon scientific fact placed at their disposal by fishery biologists regarding proper regulation of harvest by both sport and commercial fishermen and regarding other fishing and biological factors. Otherwise, legislation precedes research and subjects the fishery to unrealistic management.

One of the preliminary steps to be taken in providing data for use in management of this fishery is that of determining population magnitude and its relation to catches. Catches have increased erratically in recent years, but there is no assurance that population size has increased correspondingly. Even though complete catches were recorded for each year, they alone would not necessarily reflect population size because catch depends upon the amount of effort expended in the fishery as well as the size of the population. The true status of the

fishery in relation to the sizes of existing stocks is virtually unknown, and it is entirely possible that overexploitation of a diminishing population is in effect but unrecognized. Conversely, it is possible that greater fishing pressure can be exerted without reducing population size to a critical level.

With the procurement of complete catch and effort records from sport and commercial fisheries throughout the striped bass range, thorough tagging and recovery programs are necessary for the determination of population sizes. Numerous tagging programs have been undertaken on this species, but the experimental design of the programs has been limited largely to the study of migrations and has failed to incorporate the type of data necessary for scientific evaluation of the populations. Acceptable exploitation rates cannot be prescribed until the relationship of catch to abundance is established.

Systematic sampling of catches and subsequent aging by the scale method are necessary in determining the composition and abundance of exploitable fish by age groups. The determination of sex ratios among age classes through sampling of catches also deserves attention if the fullest interpretation of population dynamics, fish movement, and spawning activity are to be made.

Striped bass are noted for being subject to occasional super increases in abundance such as those which were produced in the middle Atlantic area in 1934 and in 1940 and which appeared in the fisheries in 1936 and 1942. Presently little is known concerning the causative factors which influence such outstanding production and/or survival. Abnormal abundance becomes obvious when a group of fish reach the age of exploitation after which time the particular age class can be kept under observation during several fishing seasons for the analysis of the effects of fishing and natural mortality upon the stocks. However, a problem whose elements are more obscure and hence less simple is that of appraising the effect of a combination of biological influences upon actual spawning production and the development of ova, larvae, and immature fish. In short, we have seen that there have been years in which abundant year classes occurred in nature, the responsible factors for which have not yet been fully determined and which warrant investigation.

Another development which now faces striped bass, as well as other anadromous species, is the rapid shrinkage of spawning and nursery rivers and estuaries being brought about by industrial expansion. This type of expansion is, of course, vital and must continue, but in many cases the stream conditions altered by industry can be made compatible with the spawning and maturing requirements of striped bass. Prog-

ress of this order is being made in some instances and is discussed later in regard to a specific case.

The above points appear to be those which are demanding the most immediate attention insofar as striped bass research is concerned. Future scientific programs designed toward obtaining such information will increase our knowledge of the dynamics of striped bass populations and consequently will benefit those engaged in the fishery.

Status of Biological Research

Prior to 1952 there were several valuable investigative programs devoted to the study of the life history of striped bass. Raney (1952) reviewed publications resulting from these programs and summarized the research and conclusions of the various investigators. He also suggested lines of research to be followed in future programs. Merriman (1941) published his report concerning striped bass studies which were made on the Atlantic coast and which dealt with several aspects of striped bass biology. These reports, in our opinion, have become two of the more valuable contributions since they have served as bases for some of the current work on this species and define problems which are considered crucial now even after the lapse of several years.

In 1954, seven east coast states joined in a co-operative study under the name of the Atlantic States Cooperative Striped Bass Program. The individual projects of these states were financed largely through Dingell-Johnson funds and were designed to encompass a wide range of biological studies. Investigations were conducted in regard to the racial composition of populations; size, age, and sex composition; fecundity; food and growth; physiology; migrations; catch and effort; delimiting of spawning areas; morphology of young; the degree of competition between several forms of sport fishing; and landlocked populations of reservoirs.

Some of the above projects have been brought to completion. Some are still in progress and the results will be published. Unfortunately though, many were ill-fated as a result of insufficient funds and personnel and, in a few isolated cases, distinterest. The fact that effort expended in striped bass research has been reduced by the simultaneous study of other fish has also detracted from the program. Conclusions reached from the more productive studies under the co-operative program, in conjunction with the valuable knowledge obtained by such workers as Merriman (1941), Vladykov and Wallace (1952), Pearson (1938), Hollis (1952), Raney (1952), Lewis (1957), and others can be utilized in more detailed population analyses such as

those now in progress in North Carolina and Chesapeake Bay. These analyses will form the basis for management recommendations.

The specific investigation with which the author is most familiar is that of North Carolina striped bass. This program was begun in 1955 as a co-operative venture between the U. S. Fish and Wildlife Service and twelve other state, federal, industrial and educational agencies. Current studies here are noteworthy because they involve problems similar to those existing in other segments of the striped bass range and because they exemplify the progress which can be made through unified effort.

The investigation was designed to evaluate the effect of industrial and domestic pollution of the spawning grounds in the Roanoke River, believed to be the dominant striped bass spawning area in North Carolina, determining: (1) the maximum concentration of pollution loads which would yet allow successful spawning; (2) minimum flow rates regulated by two recently constructed dams which would allow successful spawning as regards space and time requirements; (3) estimates of abundance in Albemarle Sound and in the spawning migration through tagging and recovery programs; and (4) the fishing intensity and spawning escapement in all areas concerned through the compilation of catch and effort data.

Even though all phases of the study are not yet complete, the population size, fishing rates and spawning escapement have been determined for each of two years; the spawning and nursery areas have been defined and flow requirements on the spawning grounds have been partially established.

Industrial officials in many instances show a willingness to co-operate in the maintenance of adequate physio-chemical conditions for fisheries when they are brought into close contact with fishery problems caused at least in part by the operation of their plants. In the Roanoke River situation, one of the primary manufacturing concerns involved has already, as a result of the fishery research program, installed expensive washing and recovery equipment for the reduction of pollutants and has contributed financial and scientific support to the study. Furthermore, the concerns which produce electric power have re-regulated flows during the striped bass spawning season at the request of scientific investigators. This action has constituted a direct financial contribution in the form of power loss. A weir has been constructed in the reservoir ahead of one of the dams to retain bottom water which is deficient in oxygen, and to draw only from the upper 25 feet of water as it moves into the forebay. The latter was done in an attempt to maintain dissolved oxygen above the minimum tolerance

level of the migrating fish in the face of biochemical oxygen demand placed on the stream by industrial effluent. The weir was constructed at a cost of approximately a quarter of a million dollars.

After completion of the study, neither the fishery nor the industries involved will be able to operate exactly as they did prior to inauguration of the study, but it is anticipated that both will be able to exist compatibly with no great loss to either interest.

In the Albemarle Sound commercial fishery, which harvests some 600,000 pounds of striped bass annually, catches of all fishing gear have been sampled systematically for two and one-half years for the determination of size, age, and sex composition. One of the more urgent issues which has come to light in this phase of the study, and one which is being given particular emphasis by striped bass researchers, is that of determining the most advantageous age at which exploitation of the fishery should begin. Such an issue is frequent in our fisheries and always deserves careful consideration. The present fishery harvests fish chiefly in the 12- to 18-inch (fork length) size classes and in their second through fourth years of age.

During the period in which the Albemarle Sound fishery has been observed, it has been found that fish entering their second year represented 25 to 60 per cent of the total catch, varying with the fishing season. Gill nets dominate the fishery, and because of their range in mesh size (3¾ to 4¼ inches), they capture the two-, three-, and four-year-old fish in large numbers. Distribution of the nets is such that they take advantage of the age classes represented by the largest number of fish available at a particular time. For instance, small-mesh nets are employed more intensely than large-mesh nets during periods of a fishing season when availability of small fish is pronounced.

Among the minor gear, purse nets catch overwhelmingly two-year-old fish because the operation of this gear is designed to take advantage of the schooling tendency of the younger fish. Haul seines sample the entire range of age classes as they are distributed in the area of catch, and approximately one-third of the catches examined thus far have been composed of two-year-old fish. Pound nets take the two-year fish predominantly either because the older fish have little tendency to lead into traps or because their density in the pound net area (the eastern end of the sound) is not great enough to allow a significant harvest.

In view of the age classes available to and caught by the various gears mentioned, the question then to be considered is the effect that an increase in the age of initial exploitation would have on the fishery in future years. Merriman (1941) has shown that by shifting the first

year of exploitation from the two- to the three-year class of fish, an increase results in pounds of fish, price per pound and, subsequently, in the total value of the fishery with no increase in expenditure of effort. Such a re-regulation in harvesting tactics in Albemarle Sound would very possibly result in at least a temporary increase in value of the striped bass, but its effect upon future abundance remains to be investigated. The magnitude of natural mortality and the amount of migration out of the sound occurring in fish after age two would, of course, have considerable bearing upon such a decision. If it were great, then a loss would result to North Carolina fishermen in failing to take advantage of the younger fish. The following analogy by Graham (1935) depicts the problem aptly: "For example, the hay crop of species maturing in different weeks must yet be cut at a certain age which takes advantage of as much growth as possible and avoids as much 'mortality' by seeding as possible."

Information furnished the legislator in regard to the management of striped bass populations therefore should not end in telling him that he can eliminate a given year class, and that it is then left up to him to decide how such action would benefit the fishery. He should also be informed as to how the change will affect subsequent populations and catches. Mathematical models have been and are being evolved which, when properly used, give a much more objective and accurate estimate of changes than has ever before been possibile. Such models are designed to be employed in the treatment of mass data analysis.

Problems exist in the Chesapeake Bay striped bass fishery which are somewhat analogous to these in North Carolina. Similar gears are employed in the two areas, and the size classes of fish caught are similar. Perhaps the greatest difference (and this is an assumed difference) between this fishery and the other one described, is that Chesapeake Bay contributes greater numbers of fish to areas outside of the Bay than does Albemarle Sound. It has been theorized that probably no more than 10 per cent of the stock migrates outside of the Bay, but that this migrating segment represents 90 per cent or more of the supply available to fishermen in northern coastal states. (Fishery Resources of the U. S., 1945). Merriman (1941) believed that the large group of two-year-olds observed in North Atlantic waters in 1936 were produced in 1934 in Chesapeake Bay. The findings of other workers supported this theory. Should this be the case, then some loss of fish outside of Chesapeake Bay might be expected by capture or natural mortality during migration away from and back to the Bay. Population density outside the Bay could at the same time be so reduced because of the extensive range of migration and relatively un-

restricted area available to the fish, that this segment of the population could not be exploited to the best advantage. The extent of migration from the Bay has not yet been proven fully. This must be accomplished since conclusions from such a study will have bearing upon the manner in which Chesapeake Bay striped bass should be harvested.

A co-operative investigation of this fishery is now in effect between the States of Maryland and Virginia and the U. S. Fish and Wildlife Service. The program is designed to determine the degree of contribution of Chesapeake Bay stocks toward those of other areas and the effects of exploitation within the Bay on its own stocks. The co-operative program has been in effect for one year, and some 3,200 striped bass have been tagged, representing the largest simultaneous striped bass tagging operation in the history of Chesapeake Bay. From the low percentage of outside of the Bay recaptures, early indications from the tagging study are that the cotnribution by Chesapeake Bay stocks to the migrant populations of other areas is, in fact, a small fraction of those produced in Chesapeake Bay.

It is anticipated that upon completion of a few years' study of the Chesapeake Bay stocks and their relationship to other populations, solution can be reached for the problems involved here, and that a plan can be developed for the best utilization of the fishery.

SUMMARY

In this presentation I have attempted to define a few of the more outstanding problems existing among the Atlantic Coast striped bass fisheries and the methods being applied toward their solution. Much time and effort have been expended by researchers for the past several years in obtaining biological data which can, in conjunction with the results of present studies, be used to develop standards for the management of the fishery. Some assumptions have been made which require further research so that their accuracy may be accepted or rejected, and new problems requiring solution are constantly being produced by man-made environmental changes. Striped bass researchers now engaged in the study of population dynamics believe that with a continued comprehensive research program they will be able to suggest measures for the most efficient utilization of the striped bass resource.

After completion of the comprehensive study, the continuance of routine systematic collection of data in regard to catch, fishing effort, age, growth, and sex ratios is not only desirable, especially where there are significantly large populations, but is necessary for successful management. After management criteria have once been established,

the collection of such data yields high dividends for the time and cost involved.

LITERATURE CITED

Graham, Michael
1935. Modern theory of exploiting a fishery, and application to North Sea trawling. Conseil Permanent International pour L'exploration de la Mer. Jour. Du Conseil. 10(3): 264-274.
Hollis, E. H.
1952. Variations in the feeding habits of the striped bass, *Roccus saxatilis* (Walbaum), in Chesapeake Bay. Bull. Bingham Oceanographic Collection, 14(1): 111-131.
Lewis, Robert Minturn
1957. Comparative study of populations of the striped bass. Spec. Sci. Rept.—Fisheries, U. S. Fish and Wildl. Serv. 204: 1-54.
Merriman, Daniel
1941. Studies on the striped bass (*Roccus saxatilis*) of the Atlantic Coast. Bull., U. S. Fish and Wildl. Serv. 50: 1-77.
Pearson, J. C.
1938. The life history of the striped bass, or rockfish, *Roccus saxatilis* (Walbaum). Bull., U. S. Bur. Fisheries, 49(28): 825-851.
Raney, Edward C.
1952. The life history of the striped bass, *Roccus saxatilis* (Walbaum). Bull. of the Bingham Oceanographic Collection. Vol. XIV, Article 1: 5-97.
U. S. Senate
1945. Fishery Resources of the United States. In Letter of the Secretary of the Interior. 79th Congress, Document No. 51, 1-135.
Vladykov, Vadim D., and David H. Wallace
1952. Studies of the striped bass, *Roccus saxatilis* (Walbaum), with special reference to the Chesapeake Bay region during 1936-1938. Bull. Bingham Oceanographic Collection, 14(1): 132-177.

DISCUSSION

DISCUSSION LEADER FAHY: When the North Carolina cooperative phase of the striped bass program was set up, it was hoped at that time that it would serve as a model for such cooperative projects in the future, and that results would be commensurate with the effort. I believe that with the completion of its work in the fall of 1958, those hopes will have been realized. A large part of the credit for that will go to the personnel of the U. S. Fish and Wildlife Service at Beaufort, who, in the refinement of their methods of study of fishery population dynamics, have gone a long way toward pinpointing these populations and giving us these estimates in mortality.

PROGRESS IN ATLANTIC COAST SHAD INVESTIGATIONS—MIGRATIONS

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The Marine Laboratory, University of Miami

Progress in Atlantic Coast Shad Investigations—Migration

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In 1950, at the request of the Atlantic States Marine Fisheries Commission, the U. S. Fish and Wildlife Service began a study of the Atlantic Coast shad (*Alosa sapidissima*). This project was undertaken to determine causes of fluctuations in abundance of this species and methods of controlling and predicting the size of shad runs. We were remarkably successful in achieving these objectives for rivers where records of the shad catch each year and the amount of gear used each year in making that catch were available (Fredin 1954; Talbot 1954).

Much of the research depended upon estimation of the total populations of shad in the rivers being studied. The estimates were determined through tagging programs in which ratios of tagged to untagged fish sampled in catches were applied to total numbers of fish tagged so that total numbers of fish in the populations were derived. Usually between 40 and 50 per cent of the tags applied were recovered within the river of tagging. Some of those tagged fish which were not caught in the rivers and which escaped other mortalities were recaptured elsewhere, and from these, as well as recaptures from other tagging experiments, the oceanic migration pattern of shad became known.

The shad is an anadromous fish, running up coastal rivers to spawn. Its river life is rather well known. Shad begin running into the St. Johns River in Florida (which is the southern range of this species) as early as November. The runs begin in more northern streams at progressively later dates. For instance, shad enter Chesapeake Bay streams in February and March, the Hudson River in April, and the St. Lawrence River (the northern limit of the species) in June. While in the river, the females deposit an average of about 250,000 eggs. These are deposited loosely in the water and are then fertilized by the males. After absorbing water, the fertilized eggs sink to the bottom and are carried along by the current. The eggs hatch in three to ten days, depending upon

water temperature. The young shad stay in the rivers until fall and when they are three to five inches in length they migrate to the sea. After spawning, the adults, if they escape fishing and natural mortalities, migrate to sea. Where they go after leaving the rivers and where the young remain until they return as

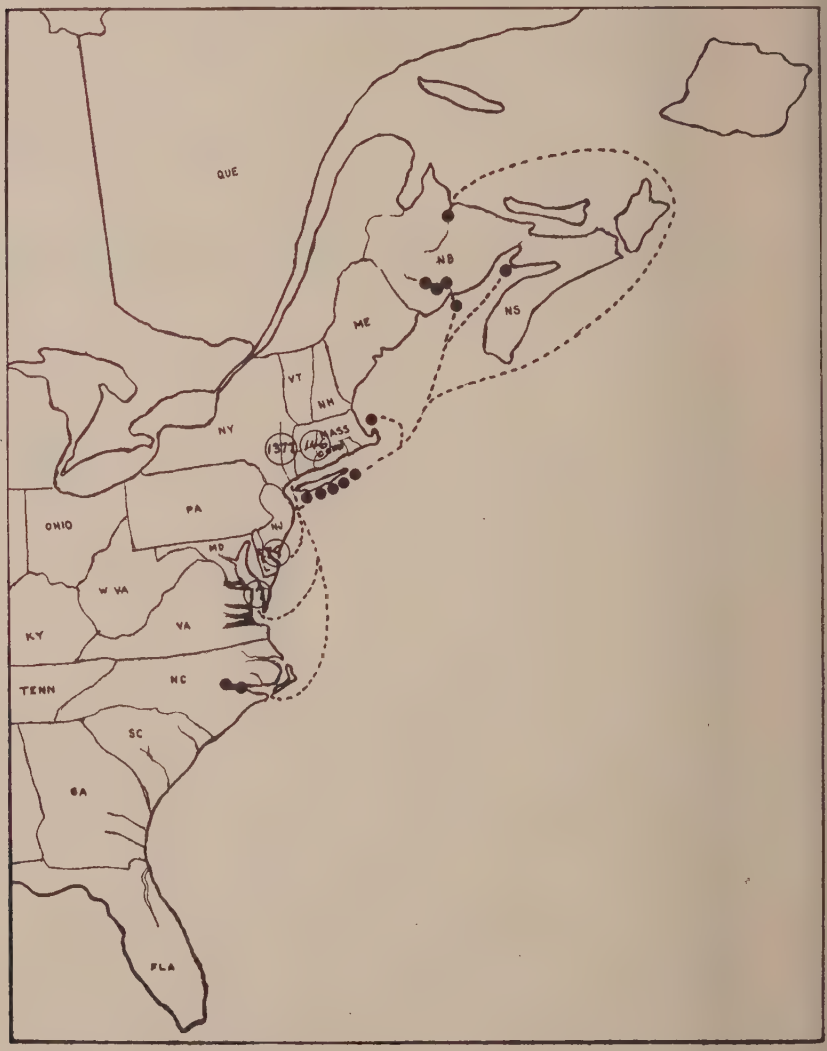

FIGURE 1. Tags recovered before or during the spawning period from tags affixed at Fire Island, Staten Island and the New Jersey Coast. Black dots indicate one tag recovery whereas numbers in circles indicate a larger number of recoveries.

adults, has always been a mystery and the subject of several hypotheses.

It was originally thought because these fish were first seen each year in the

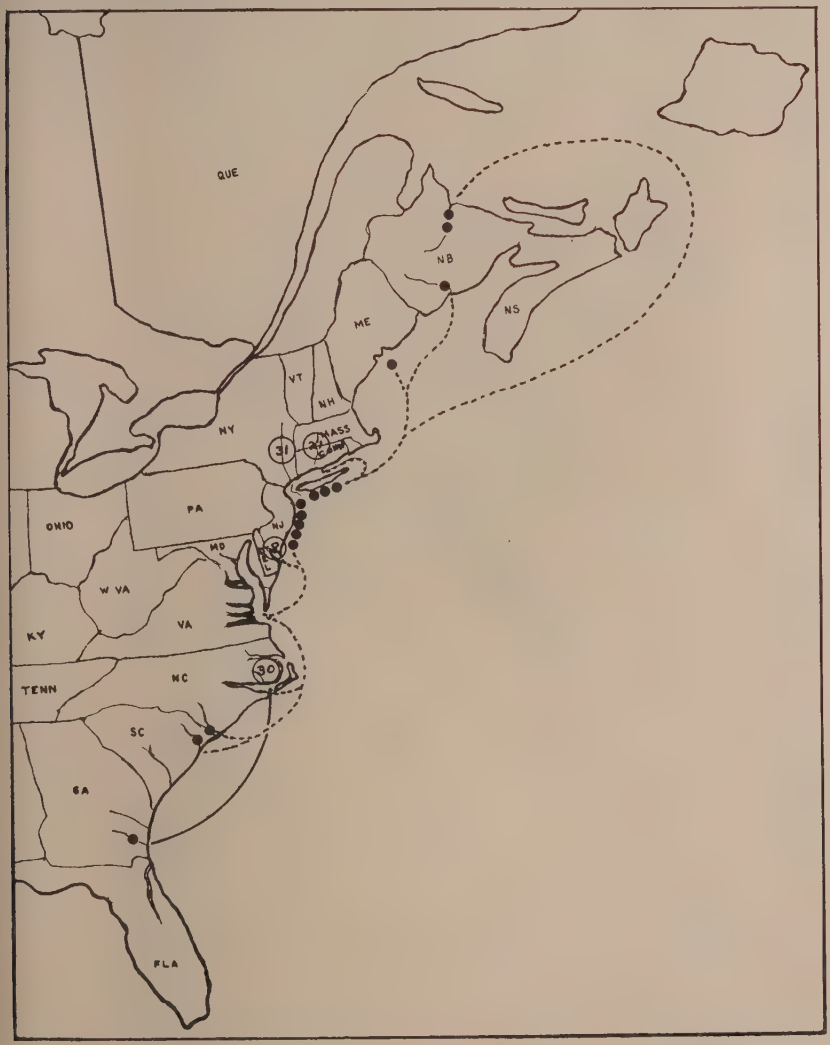

FIGURE 2. Tags recovered before or during spawning from tags affixed in Chesapeake Bay and tributaries and from tags affixed at the mouth of the Neuse River in North Carolina. Black dots represent one recapture and numbers in circles indicate a larger number of recoveries. The dashed line indicates migration of Chesapeake Bay tagged shad while the solid line indicates migration of shad tagged at the mouth of the Neuse River.

south, that they wintered there and started northward each spring in a vast school, sending detachments into each successive stream as they passed, the last of them entering the St. Lawrence River. A later theory was that the adults, and later the young, moved out of the rivers and remained in the ocean near the mouths of the rivers where they were born and entered the rivers again when the water temperature became suitable. Tag returns, however, have shown

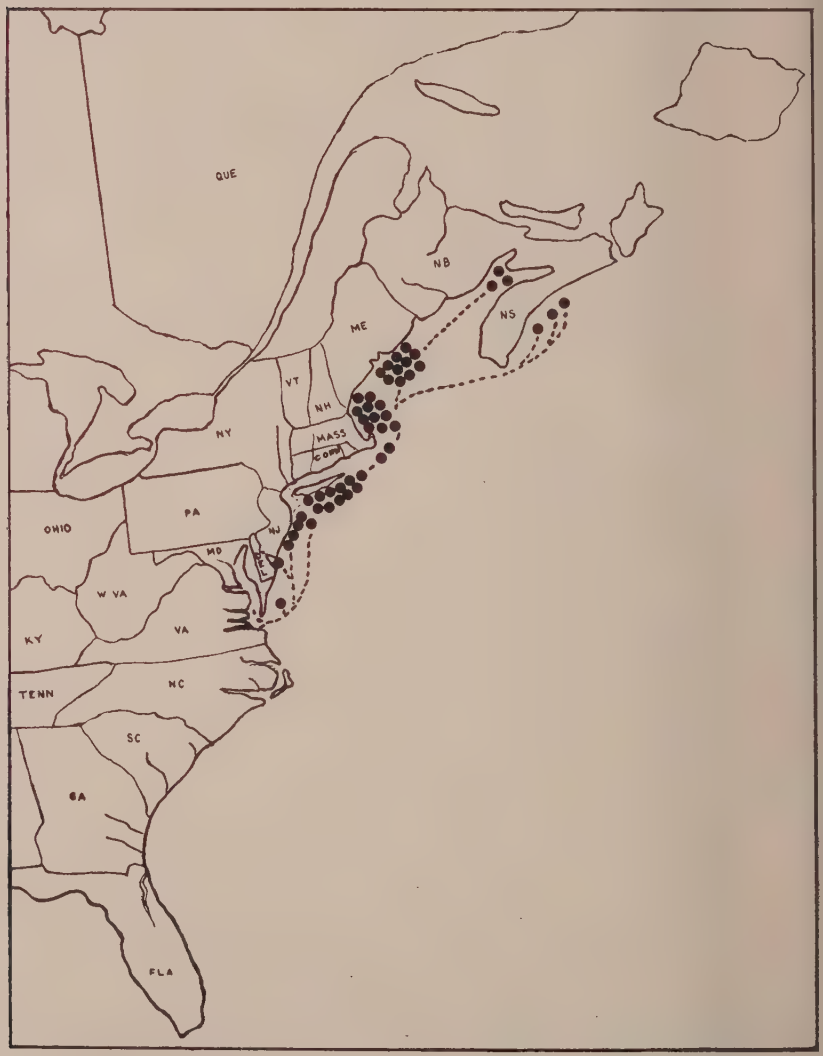

FIGURE 3. Tags recovered after the spawning period from all spring tagging programs.

that shad undertake a regular migration pattern each year which does not bear out either of these hypotheses.

The returns from a total of 17,508 tags applied to shad at many locations along the Atlantic Coast between 1938 and 1955 were used in this study. A total of 6,846 tags, or 39 per cent, of these were recovered.

Most of the tagging was carried out in the spring of the year during the

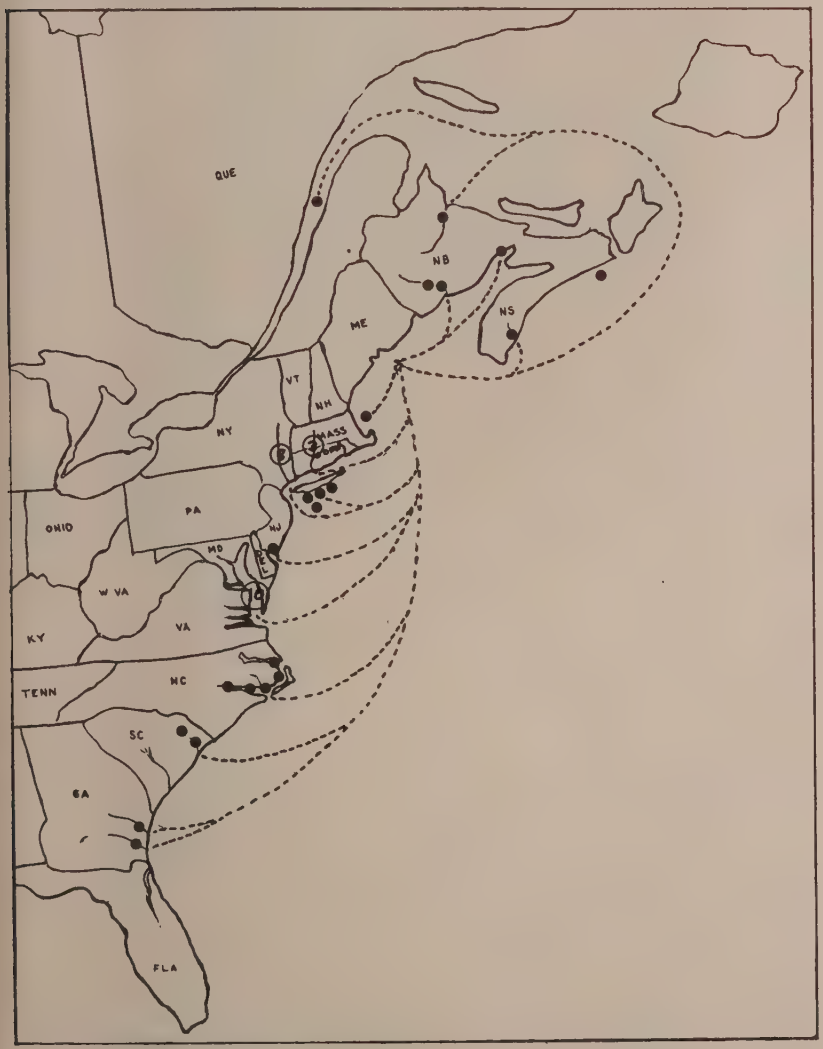

FIGURE 4. Tags recovered from tags affixed in the Gulf of Maine during the summer.

spawning run, but some were tagged off the coast of Maine during the summer months. Table 1 shows the locations where shad were tagged, the number tagged, and the number recovered. For the purpose of analyzing the tag returns from the spring tagging projects, they were separated into two categories. These are:

1. Recoveries made before or during the spawning period.
2. Recoveries after spawning.

The above separation was based on a knowledge of the spawning periods in each of the rivers. The date, May 31, was arbitrarily chosen as the latest that shad would be spawning south of Long Island and June 14 north of Long Island. The shad tagged in the Gulf of Maine were analyzed in a third category.

Figure 1 shows the pattern of migration of shad tagged at Fire Island and Staten Island, New York, and the New Jersey coast from March through June and recovered before or during the spawning period. The bulk of the shad caught and tagged in this area were heading for the Hudson River where 1,377 returns were made and to the Connecticut River where 146 were recaptured. Some, however, were recaptured south of New Jersey—nineteen in Delaware Bay and tributaries, seventeen in Chesapeake Bay and tributaries, two in North Carolina waters, and several north of New Jersey as far as the Bay of Fundy and Mirimichi River in Canada.

Figure 2 shows the recoveries of shad tagged in the spring in Chesapeake Bay and recaptured elsewhere before June 1. Those recovered in Chesapeake Bay and tributaries were of course in the majority—some 1,700—but are not shown since they show no migration. Those migrating out of the Bay and recaptured before or during spawning were recovered in the ocean and streams from South Carolina to New Brunswick, Canada. Also shown in this figure is the migration of a shad tagged at the mouth of the Neuse River, North Carolina, and recovered in the Altamaha River in Georgia. Here too, the bulk of the Neuse River tagged fish were recaptured in the river of tagging.

TABLE 1

SHAD TAGGED AND TAGS RECOVERED

Place tagged	No. tagged	No. recovered
Gulf of Maine	601	44
Connecticut River	2,542	612
Fire Island, New York	198	49
Staten Island, New York	1,054	478
Hudson River	3,295	1,321
New Jersey Coast	3,421	1,263
Chesapeake Bay and tributaries	4,775	2,514
Neuse River, North Carolina	377	226
Edisto River, South Carolina	128	16
Ogeechee River, Georgia	235	133
St. Johns River, Florida	882	190
Totals	17,508	6,846

The tag recoveries shown in these two figures indicate that, in general, most of the shad caught in the spring of the year at each location are heading toward the nearest spawning streams in the area, but with them are shad bound for other places along almost the entire range of the species.

Figure 3 shows recoveries from all tagging programs made after the spawning period—that is, after May 31 at Long Island and southward, and after June 14 north of Long Island. All recaptures were made north of the tagging sites from shad which were either in the Gulf of Maine or apparently on their way there. The recaptures near Long Island were made between June 5 and 26. Those captured off Massachusetts were made between June 22 and November 3, but none was recaptured during September. In Maine and Canadian waters the recoveries were made only during July, August, and September. This indicates that shad are caught during June, July, and August as they migrate past Massachusetts on their way north into the Gulf of Maine region, and again during October and November on a southern migration. Vladykov (1950, 1957) has reported that shad tagged in the St. Lawrence River during the spawning run also migrated to the Gulf of Maine during July and August. Not a single tag affixed to shad in streams south of the Chesapeake Bay area was recovered after the spawning period.

Recoveries of tags affixed in the Gulf of Maine are shown in Figure 4. These were tagged during August and September, and all recoveries were made the following spring except the one in Massachusetts which was recaptured in the fall approximately two months after tagging. As can be seen, shad tagged in the Gulf of Maine area were later recaptured throughout the entire range of the species except for the St. Johns River in Florida. Since the number of fish tagged was small and the recapture spread along the entire coast, we believe the lack of recaptures in the St. Johns River is probably the result of chance rather than an exception to the general pattern.

Since none of the adult shad tagged in streams south of Chesapeake Bay was ever recovered outside the rivers, the shad tagged in Maine which entered the southern rivers must have been immature when tagged. This leads to the conclusion that young shad migrate to the Gulf of Maine for the summer as well as adult fish. Atkins (1887) and Bigelow and Welsh (1925) reported large numbers of both large and small shad in the Gulf of Maine, but these writers at the time thought they were shad from Maine streams. In recent years, however, there have been few shad in Maine streams because of dams and pollution (Taylor, 1951), but still large numbers of shad are found in the Gulf of Maine each year. The migration to this area by shad from all other Atlantic Coast shad streams undoubtedly accounts for the large numbers found in the Gulf of Maine during the summer months.

Not much is known about where these fish spend the winter months since only one tag has been recovered during December and January. This was recovered in the ocean off New Jersey. Shad appear in abundance, however, along the middle and south Atlantic Coasts beginning in February, and it is assumed that they spend the winter here, probably in deep water. Some evidence of this was found when shad were caught in forty to fifty fathoms of water off North Carolina in March, 1958 by the U. S. Fish and Wildlife Service vessel, *Delaware*. When shad appeared in abundance along the middle and south Atlantic Coast, tagged shad from all areas were with them. For instance, shad tagged in the St. Lawrence River by Vladykov were recovered the following spring as far south as Chesapeake Bay, and those tagged on the spawning grounds of the Hudson River were recovered the following spring as far south as North Carolina. However, 185 Hudson-tagged fish returned to the Hudson, and twenty-three Connecticut-tagged shad returned to the Connecticut, but not

a single tag was found on the spawning grounds of any other stream. This indicates that although shad may migrate many hundreds of miles in the ocean, they return to the same stream to spawn the following year.

Considerable evidence is available to show that shad return to their native stream to spawn. Hollis (1948) and Coker inserted small plastic tags into the belly cavities of juvenile shad. These were released in two areas—one in North Carolina and the other in Maryland. In each case the few returns received three, four, and five years later from mature adult shad came from the area of release or from fish that could have been on their way there. None was returned from an area that would indicate that they might spawn in any place but their "home" stream.

Further, Hammer (1942) made a study of the scales and measurements of shad from tributaries of Chesapeake Bay and found significant differences in shad from various streams, indicating separate populations that return to spawn in the stream of their origin.

As previously noted, shad tagged in rivers south of Chesapeake Bay are never recovered after the spawning period. An examination of the scales from these fish shows that they are spawning for the first time, and hence it can be assumed that they die after spawning. Scales from shad spawning in the more northern streams show that 27 to 50 per cent of the fish are spawning for the second or more times. This is good evidence that few, if any, shad of the northern populations stray into and spawn in the southern streams.

It has also been shown (Fredin 1954; Talbot 1954) for some shad streams that the size of run in each stream is dependent upon the number of shad previously spawning. In other words, each of the runs in a shad stream is self-perpetuating and fluctuates independently of shad runs in other streams. This could only occur if the majority of the shad return to their home stream. The available evidence, therefore, indicates that most shad do return to their native stream to spawn.

From the data presented, we can summarize the migration pattern of Atlantic Coast shad. After spawning, adult shad in streams from Chesapeake Bay and northward migrate to the Gulf of Maine and spend the summer and fall there. Little evidence is available as to where they spend the winter months, but it is presumed that this period is spent in deep water in the middle and south Atlantic area. Beginning in January or February as the spawning season approaches, shad move inshore, and some are taken by the coastal commercial fisheries. They then migrate either north or south to their native streams and spawn, repeating this cycle if they escape natural and fishing mortalities. The young shad leave their native streams in the fall; probably spend the winters in the middle Atlantic area; migrate to the Gulf of Maine each summer along with the adults; and when mature, return to their native streams to spawn. Those that spawn in streams south of Chesapeake Bay, and particularly south of North Carolina, die after spawning.

Knowledge concerning the migration of this fish is not only interesting from a life-history standpoint, but is also useful in the management of the species. In our investigations we have shown that over 80 per cent of the variations in size of populations studied can be accounted for by changes in size of the spawning populations in previous years. The balance of changes can be attributed, partly at least, to variations in the catches outside the rivers. Shad are not fished extensively in the Gulf of Maine because only the female shad bring good prices,

and almost all of the shad in the Gulf of Maine are either immature or spawned out. However, during the last war when fish prices were high, over a million pounds were landed. Again in 1957, fishermen in the Gulf of Maine turned to shad when menhaden failed to appear, and over two million pounds of shad were landed during the summer months. Landing figures of all shad catches outside the usual fishing sites, now that we know the migration pattern, should enable us to better our control of population size and to make even better predictions of abundance than we have previously been able to do.

LITERATURE CITED

Atkins, C. G.
1887. The river fisheries of Maine. *In* Goode, G. Brown and associates, the Fisheries and Fishery Industries of the United States, Sect. 5, vol. 1, 808 pp.

Bigelow, Henry B., and William W. Welsh
1925. Fishes of the Gulf of Maine. U. S. Bureau of Fisheries, Bull., vol. 40 (1924), Pt. 1, 567 pp.

Fredin, Reynold A.
1954. Causes of fluctuations in abundance of Connecticut River shad. U. S. Fish and Wildlife Service, Fishery Bull., vol. 54, No. 88, pp. 247-259.

Hammer, Ralph Curtis
1942. The homing instinct of the Chesapeake Bay shad *(Alosa sapidissima,* Wilson) as revealed by a study of their scales. Thesis, University of Maryland, 45 pp. (Typewritten).

Hollis, E. H.
1948. The homing tendency of shad. Science, vol. 108, No. 2804, pp. 332-333.

Talbot, Gerald B.
1954. Factors associated with fluctuations in abundance of Hudson River shad. U. S. Fish and Wildlife Service, Fishery Bull., vol. 56, No. 101, pp. 373-413.

Taylor, Clyde C.
1951. A survey of former shad streams in Maine. U. S. Fish & Wildlife Service, Special Scientific Rept.: Fisheries No. 66, 29 pp.

Vladykov, Vadim D.
1950. Movements of Quebec shad *(Alosa sapidissima)* as demonstrated by tagging. Naturaliste Canadien, vol. 77, Nos. 5-6, pp. 121-135.
1957. Distant recaptures of shad *(Alosa sapidissima)* tagged in Quebec. Naturaliste Canadien, vol. 83, No. 10, pp. 235-248.

SUMMARY OF ATLANTIC COAST SHAD INVESTIGATIONS — 1950-57

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The U. S. Fish and Wildlife Service, as the primary research agency of the Atlantic States Marine Fishery Commission and at its request is conducting an investigation of the Atlantic coast shad fishery. Objectives of this study are to (1) determine the causes for the decline in the fishery, (2) determine conditions favoring recovery of the runs, and (3) provide information for proper management to obtain maximum continuing yields. Research is conducted in different areas each years since funds and personnel are insufficient for a simultaneous investigation of the entire fishery. This report is a brief summary of our major research findings during the period 1950-57.

Maine Streams

The disappearance of shad from the rivers and streams of Maine was almost entirely the result of their exclusion from spawning areas by dam construction and pollution in the river estuaries. Only two streams, the Nonesuch and the Sheepscot, still contain remnant shad runs. Three streams, the Eastern, the Cathance, and the Abagadasset, formerly contained shad runs and appear suitable for stocking when and if such measures are warranted.

Connecticut River

Research on this shad fishery was begun in 1951. The results of this investigation revealed that the size of the shad population was dependent upon the number of shad allowed to escape the fishery and spawn. When over-fishing occurs, the number of shad available to spawn is small, and as a result subsequent shad runs are small. When spawning populations are large or adequate, subsequent runs are large. From data obtained in the 1951 study and past years catch and effort data, it is possible to predict the size of the shad population one year in advance. Therefore, fishing effort can be regulated to provide adequate escapement of spawners and produce maximum continuing yields.

The sport fishery for shad on the Connecticut has increased tremendously since 1951. The growth of this fishery in relation to the commercial fishery must be followed so that proper management can be carried out.

A fishway to pass shad over Hadley Falls Dam at Holyoke, Massachusetts, has been operating for several years. The effect of increasing the shad spawning and nursery area on the size of the Connecticut River shad population is being studied.

Hudson River

Our 1950 and 1951 studies on this river indicated that this shad population could also be managed to produce maximum continuing yields. Since 1950 the fishing rate has decreased with a large increase in the number of fish allowed to spawn. As a result this population has increased tremendously during the past few years and is now approaching its previous high level. The yearly collection of catch and effort data on this fishery is necessary to enable the continued study of the dynamics of this population.

Delaware River

Research conducted on this river's shad population in 1951 indicated that pollution in the Philadelphia-Camden area was responsible for all but destroying the run. During the past few years, through the efforts of the Interstate Commission on the Delaware River Basin, municipalities and industries have increased their sewerage treatment in this area. There appears to be some improvement in water quality, but dissolved oxygen is still too low to be considered safe for shad passage. However, if pollution control continues at its present rate, despite industrial expansion in this area, shad and other anadromous fish runs should soon become re-established, unless dams, currently under consideration should prove to be a further deterrent in spite of the fishways that are contemplated therein.

Chesapeake Bay

Research on this fishery was conducted in 1952. Catch and effort data were used with data obtained from tagging studies to determine the size of most of the major shad populations native to rivers tributary to Chesapeake Bay. Previous years catch and effort data were available only for the Maryland portion of the Bay, and therefore only fluctuations in the size of this population could be studied. It was found that fishing effort for shad had increased markedly despite the enactment of the Maryland Management Plan. The purpose of the Plan was to stabilize fishing effort at a relatively low level and thereby increase the size of future years shad populations. The effect of the Maryland Management Plan on its shad population is obscured because of the effect of the Virginia shad fishery on the Maryland shad population.

It was suggested that the States of Maryland and Virginia establish comparable systems to collect catch and effort data on the shad so that these basic data will be available for any future study of the Chesapeake Bay fisheries.

Neuse River

The Neuse River shad fishery was investigated in 1953 to determine catch, size of run, and spawning escapement. Because previous years catch and effort data were not available, these parameters could be determined only for the year of investigation. From a study of shad scales, it was found that less than three percent of the run had spawned the previous year. This is in marked contrast to shad populations north of North Carolina where up to fifty percent and more of a shad run may be made up of shad that have spawned the previous year.

Collection of yearly catch and effort data for a period of years is necessary before studies can proceed to determine factors limiting shad abundance in the Neuse River.

Edisto River

The Edisto River shad fishery was investigated to determine fishing effort, fishing rate, total catch, size of run and spawning escapement in 1955. These data were obtained from a tagging and recovery program and the collection of catch and effort data from both sport and commercial shad fishermen. Catch and effort records for previous years were not available on this stream; therefore, size of former runs and escapements could not be determined.

It was suggested that the State of South Carolina establish a system to collect yearly complete catch and effort records on the Edisto River. If these records are obtained for a period of years, studies can proceed to determine what factors are affecting shad abundance.

Ogeechee River

This study was conducted in 1954 to determine catch, fishing rate, population size and spawning escapement. Recommendations were made (1) for the preservation of future shad runs which may be threatened if textile mills are constructed along the lower portion of the river and (2) for the collection of yearly catch and effort data which would be used in conjunction with the 1954 data to determine factors affecting shad abundance.

St. Johns River

Catch and effort data have been collected on this shad fishery each year since 1953 when this river was first investigated. An estimate of the extensive shad sport catch on this river has also been made each year. This fishery is being investigated during the 1957-58 shad season to determine total catch, fishing rate, size of run and spawning escapement. These data will be used with the previous years catch and effort data to determine population parameters for each year these data are available. When these data have been obtained for an adequate number of years, studies to determine factors affecting shad abundance in this river can be conducted.

PUBLICATIONS

Middle Atlantic Fishery Investigations

1. **A Method of Transporting Fingerling Shad.** J. E. Sykes, Prog. Fish Cult., vol. 12, No. 3 (July, 1950), pp. 153-159.

*2. **Notes on Statistical Methods** (mimeo) R. J. Monroe, Misc. Contr. No. 1 (1950). U. S. Fishery Laboratory, Beaufort, N. C.

3. **The Transfer of Adult Shad.** J. E. Sykes, Prog. Fish Cult., vol. 13, No. 1 (January, 1951), pp. 45-46.

4. **Feeding Habits of Adult Shad (Alosa sapidissima) in Fresh Water.** C. E. Atkinson. Ecology, vol. 32, No. 3 (1951).

5. **A Survey of Shad Streams in Maine.** C. C. Taylor, Spec. Sci. Rep.: Fish. No. 66 (1951). USFWS.

6. **A Fishway that Shad Ascend.** G. B. Collins, Spec. Sci. Rep.: Fish. No. 65 (1951).

7. **Passage of Shad at the Bonneville Fishways.** G. B. Talbot, Spec. Sci. Rep.: Fish. No. 94 (1953). USFWS.

8. **Determining Age of Atlantic Shad from their Scales.** J. P. Cating. Fish. Bull., No. 85 (1953). USFWS.

9. **Fecundity of Hudson River Shad.** B. A. Lehman. Res. Rept. 33 (1953). USFWS.

10. **Experimental Transportation of Live Shad Past Susquehanna River Dams** C. H. Walburg, Spec. Sci. Rept.: Fisheries No. 114 (1954). USFWS.

11. **Causes of Fluctuations in Abundance of Connecticut River Shad.** R. A. Fredin. Fish. Bull., No. 88 (1954). USFWS

*12. **Notes on the Use of Theoretical Models in the Study of the Dynamics of Exploited Fish Populations** (mimeo). R. J. H. Beverton. Misc. Contr. No. 2 (1954). U. S. Fishery Laboratory, Beaufort, N. C.

13. **Factors Associated with Fluctuations in Abundance of Hudson River Shad.** G. B. Talbot. Fish. Bull., No. 101 (1954). USFWS

14. **Shad in the Hudson.** G. B. Talbot. New York State Conservationist (April - May, 1954).

15. **Relative Abundance of Maryland Shad 1944-52.** C. H. Walburg. Res. Rept. 38 (1955). USFWS.

16. **American Shad, Alosa sapidissima, Parasitized by Argulus Canadensis in the Connecticut River.** W. S. Davis, Jour. of Parasitology, vol. 42, No. 3 (1956).

17. **Commercial and Sport Shad Fisheries of the Edisto River, South Carolina,** 1955 C. H. Walburg. Spec. Sci. Rept.: Fish. No. 187 (1956). USFWS.

18. **Shad Fishery of the Ogeechee River, Georgia, in 1954.** J. E. Sykes. Spec. Sci. Rept.: Fish. No. 191 (1956). USFWS.

19. **Conservation of an East Coast Shad Fishery.** G. B. Talbot, Gulf and Caribbean Fish. Inst., Proc. 8th Ann. Sess., 1955, pp. 92-99.

20. **Past and Present Delaware River Shad Fishery and Considerations for its Future.** J. E. Sykes and B. A. Lehman, Res. Rept. 46 (1957) USFWS.

*21. **Comparative Study of Populations of the Striped Bass.** R. M. Lewis, Spec. Sci. Rept.: Fish. No. 204 (1957) USFWS.

22. **Observations on the Food and Growth of Juvenile American Shad, Alosa sapidissima.** C. H. Walburg, Trans. Am. Fish. Soc., vol. 86 (1956) pp. 302-306.

23. **Neuse River Shad Investigation, 1953.** C. H. Walburg. Spec. Sci. Rept.: Fish. No. 206 (1957) USFWS.

24. **Shad Fishery of Chesapeake Bay with Special Emphasis on the Fishery of Virginia** C. H. Walburg and J. E. Sykes, Res. Rept. 48 (1957) USFWS.

25. **Ova Production of American Shad in Atlantic Coast Rivers.** W. S. Davis, Res. Rept. 49 (1957) USFWS.

* Not directly concerned with the shad studies.

SHAD RESEARCH PROJECT

Other Reports made to ATLANTIC STATES MARINE FISHERIES COMMISSION by Staff Members of the U. S. Fish and Wildlife Service or by Special Committees and Publications issued by the Cooperating States — 1943-1957.

1943 **Rehabilitation of the Shad Fisheries of the Chesapeake Bay Watershed** — Report of Special Committe of Maryland and Virginia and USFWS members.

1946 **The Shad — Alosa Sapidissima** — Fishery Leaflet 179, USFWS.

1948 **Value of Various Methods for Improving Shad Fisheries of Virginia** — Louella E. Cable and Edgar H. Hollis, USFWS, Feb. 20, 1948.
Recent Decline of Shad in the Hudson River Due to Failure of Reproduction, Not to Overfishing—Seek Cause through Science — Louella E. Cable, USFWS, Feb. 20, 1948.

1949 **The Shad Program in its Relation to Incodel's Integrated Water Project** — by Wayne D. Heydecker, ASMFC, presented to Incodel June 6, 1949.

1950 **Progress Report, Chesapeake Bay Shad Study** by James Sykes, USFWS, presented to the Chesapeake Bay Section, June 9, 1950.
History and Progress of the Shad Investigations — presented by Clinton E. Atkinson, USFWS, to conference of New Jersey and Delaware Commissioners at Philadelphia, Pa.—August 15, 1950.
Summary of Activities —
Shad Investigations — By Gerald B. Talbot, USFWS, at same meeting as above.

1951 **Report of Chesapeake Bay Shad Committee** to 18th Meeting of Chesapeake Bay Section, Washington, D. C. — April 30, 1951.

Progress Report on the Shad Investigations to ASMFC by Clinton E. Atkinson, USFWS — September 6, 1951 — Appendix C, Minutes of 10th Annual Mtg.

Shad Investigations — 1951 — Report condensed by Gerald B. Talbot, USFWS, Sept. 6, 1951, to ASMFC, Appendix F, Minutes of 10th Annual Mtg.

1952 **Progress Report — Shad Investigation Program — Feb. 1951 to Jan. 1952,** USFWS, Beaufort, N. C., and

Summary of Connecticut River Shad Report — by Reynold A. Fredin, USFWS, to North Atlantic Section of ASMFC, Sept. 5, 1952 — Appendices H & I to Minutes of 11th Annual Mtg.

Summary of Shad Progress Report — by Gerald B. Talbot to Middle Atlantic Section of ASMFC, Sept 5, 1952 — Appendix J, Minutes of 11th Annual Mtg.

Shad Report — Chesapeake Bay — by R. A. Fredin, USFWS, to Chesapeake Bay Section of ASMFC, Sept. 5, 1952, Appendix S, Minutes of 11th Annual Mtg.

1953 **Report of Shad Investigations** — by R. A. Fredin, USFWS, to North Atlantic Section of ASMFC, October 9, 1953, Appendix NA-8, Minutes of 12th Annual Mtg.

Report on Shad Investigations — Middle Atlantic Area, by Gerald B. Talbot, USFWS, to Middle Atlantic Section of ASMFC, October 9, 1953, Appendix MA-3, Minutes of 12th Annual Mtg.

Report on Chesapeake Bay Shad Investigations by Gerald B. Talbot, USFWS, to Chesapeake Bay Section of ASMFC, October 9, 1953, Appendix CB-5, Minutes of 12th Annual Mtg.

Summary of Shad Studies — Virginia Fisheries Laboratory by Wiliam H. Massman, to Chesapeake Bay Section of ASMFC, October 9, 1953, Appendix CB-6 to Minutes of 12th Annual Mtg.

Report of Shad Investigations in South Atlantic Section, by R. A. Fredin, USFWS, to South Atlantic Section of ASMFC, October 9, 1953, Appendix SA-2 to Minutes of 12th Annual Mtg.

1954 **Summary of Shad Investigations,** by Gerald B. Talbot, USFWS, to North and Middle Atlantic Sections, ASMFC, October 4, 1954 — Appendix NA-MA-3, Minutes of 13th Annual Mtg.

Shad Investigations Connecticut River by Charles H. Walburg, USFWS, to North and Middle Atlantic Sections, ASMFC, October 4, 1954 — Appendix NA-MA-4, Minutes of 13th Annual Mtg.

Shad Investigations — Middle Atlantic Area, by Gerald B. Talbot, USFWS, to North and Middle Atlantic Sections, ASMFC, October 4, 1954. Appendix NA-MA-5, Minutes of 13th Annual Mtg.

Shad Investigations — Chesapeake Bay Area, by Charles H. Walburg, USFWS, to Chesapeake Bay Section, ASMFC, October 4, 1954 — Appendix CB-1 to Minutes of 13th Annual Mtg.

Shad Investigations — South Atlantic Area, by James S. Sykes, USFWS, to South Atlantic Section, ASMFC, October 4, 1954. Appendix SA-1, Minutes of 13th Annual Mtg.

Progress Report No. 4. Shad Investigation Program, USFWS Beaufort, N. C. March 1953 - March 1954.

1955 **Summary of Shad Research — North Atlantic Area,** by Gerald B. Talbot, USFWS, to North Atlantic Section, ASMFC, November 14, 1955 — Appendix to Section Minutes at 14th Annual Mtg.

Summary of Shad Investigations — Middle Atlantic Area, by G. B. Talbot, USFWS, to Middle Atlantic Section, ASMFC, November 14, 1955 — Appendix to Section Minutes at 14th Annual Mtg.

Summary of Shad Investigations — South Atlantic Area, by G. B. Talbot, USFWS, to South Atlantic Section, ASMFC, November 14, 1955. Appendix to Section Minutes at 14th Annual Mtg.

1956 **Oxygen Content of the Delaware River in Relation to Shad Rehabilitation,** by Gerald B. Talbot, USFWS, to Middle Atlantic Section, September 21, 1956. Appendix MA-3 to Minutes of 15th Annual Mtg.

1957 **Report to Members of Incodel on the Delaware River Shad Fishery,** Aug. 28, 1957, by Wayne D. Heydecker, Secretary-Treasurer, to Middle Atlantic Section of ASMFC, September 26, 1957. Appendix MA-2 to 16th Annual Minutes.

Delaware Shad Fishery Report, August 28, 1957 (to accompany above report to Incodel) by Charles E. Walburg, USFWS, to Middle Atlantic Section of ASMFC, Appendix MA-3 to 16th Annual Minutes.

Cod Growth and Temperature

By

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In studying growth phenomena in several species of fish and shellfish, I have found persistent relations between mean temperature conditions and certain growth parameters. These relations for the cod (*Gadus callarias*) seem of possible significance to biologists studying the cod fisheries and are reported here.

Biologists have frequently noted that rapid growth is, in poikilothermic animals at least, generally incompatible with a long life span and, conversely, that large size and a long life span are often associated with the cooler temperatures of high latitudes. Such qualitative conclusions are of limited usefulness, however.

From published age-length data for cod from a number of localities (Table 1), I determined the parameters of the BERTALANFFY (1938) growth equation:

$$L_t = L_\infty \, (1 - e^{-K(t - t_0)}) \qquad (1)$$

where L_t is the length at time t, L_∞ the maximum attainable size, K a constant related, in its derivation, to catabolism, and t_0 a correction on the time axis.

The parameters L_∞ and K of equation (1) may be estimated by determining the regression of length at time $t + 1$ (L_{t+1}) on length at time t (L_t) (WALFORD, 1946; BEVERTON, 1957):

$$L_{t+1} = mL_t + i \qquad (2)$$

where m is the slope of the regression line and i is the y-intercept:

$$L_\infty = i/(1 - m) \qquad (3)$$

and

$$K = -\log_e m \qquad (4)$$

If one defines life span as the time required to attain some arbitrary fraction, p say, of L_∞, then the life span, A_p, is readily derived from equation (1):

$$A_p = t_0 - \frac{\log_e (1 - p)}{K} \qquad (5)$$

Table 1

Growth parameters for cod from various localities and mean annual surface temperature estimated from World Atlas of Surface Water Temperatures, US Hydrographic Office

Locality	Source of growth data	Mean temp. °C.	Growth parameters K	i	L_∞	$A_{\cdot 95}$
Southern New England..	SCHROEDER, 1930.....	11·5	·281	24·2	98·8	10·7
Nova Scotia	MARTIN, 1953.....	7·5	·118	13·7	123·5	25·4
North Iceland.....	SÆMUNDSSON, 1923	4·6	·064	12·4	200·3	46·9
East Iceland	SÆMUNDSSON, 1923	5·4	·096	13·4	146·6	31·3
South Iceland.....	SÆMUNDSSON, 1923	8·0	·219	21·6	109·6	13·7
South-west Iceland.....	SÆMUNDSSON, 1923	6·7	·147	17·4	127·6	20·4
North-west Iceland	SÆMUNDSSON, 1923	5·6	·080	14·4	188·5	37·7
North Sea	GRAHAM, 1934.....	9·6	·167	22·0	143·5	18·0
Lofoten	ROLLEFSEN, 1934	8·4	·284	23·5	95·9	10·6
North Norway.....	JENSEN and HANSEN, 1931..	6·3	·069	10·2	154·0	43·7
Barents Sea.....	TROUT, 1949.....	5·7	·109	13·8	134·0	27·6

Defining life span as the time required to attain 95% of L_∞ (TAYLOR, in press), equation (5) becomes:

$$A_{\cdot 95} = t_0 + \frac{2{\cdot}996}{K} \qquad (6)$$

Table 1 shows the results of applying equations (1) to (6) to some cod-growth data selected from the literature to cover a wide range of latitudes and temperature conditions. The latter were estimated from information in the World Atlas of Sea Surface Temperatures (Hydrographic Office of the US Navy, 1944).

Annual mean surface temperature is, of course, only a rough indication of the thermal environment of the cod. Furthermore, much excellent growth data for cod exist which have not been used because the monthly temperature information in the World Atlas does not seem sufficiently definitive. This is especially true of areas where sea ice is present during several months of the year (west coast of Greenland), and in areas largely surrounded by land masses or with unusual hydrographic conditions (Skagerak-Kattegat-Baltic Sea areas). It will be noted also that a substantial portion of the data are from the Icelandic area. The hydrographic conditions indicated by surface temperatures around the coast of Iceland appear distinctly different, which makes them as useful for the present analysis as two areas as widely separated, for example, as the southern New England area and the Barents Sea. The differences in growth parameters suggest also, at the time the data were collected at least, a high degree of independence of stocks of cod around Iceland.

On the hypothesis that growth parameters are indices of physiological activity, a linear relation between the logarithm of temperature and the logarithms of the growth parameters K and i might be expected (cf. Q_{10} relations). The expected linearity appeared, (Figures 1 and 2), fitted by the regression equations:

$$\log K = 1{\cdot}6427 \log T - 2{\cdot}2593 \qquad (7)$$

and

$$\log i = 0{\cdot}8573 \log T + 0{\cdot}4973 \qquad (8)$$

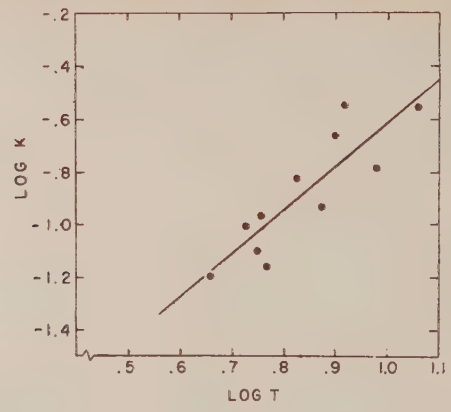

Figure 1. Relation of the growth parameter K (equation 1) to mean annual surface temperature at the localities listed in Table 1.

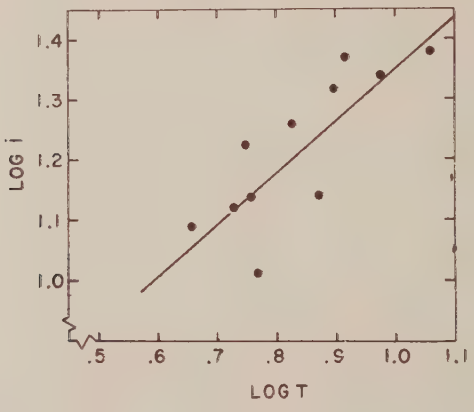

Figure 2. Relation of the growth parameter i (equation 2) to mean annual surface temperature at the localities listed in Table 1.

The correlation coefficient between log T and log K is 0·880; between log T and log i, it is 0·812 (the 1% level of significance, 9 d.f., is 0·735).

Applying equations (7) and (8) to the surface temperature range 4° to 12°C., I have estimated (Table 2) values of i and K and, by means of equations (3), (4), and (6), the corresponding maximum sizes (L_∞) and life spans ($A_{\cdot 95}$). These are shown graphically in Figure 3.

One notes in Table 2 that slight differences in temperature indicate wide differences in expected maximum size and life span. A change in the average annual temperature from 4° to 5°C., for example, produces a decrease in L_∞ of 29 cm. and a decrease in life span of 18 years.

The disappearance of the larger and older fish from an exploited population, and the resulting decrease in the average size of fish caught, is usually attributed

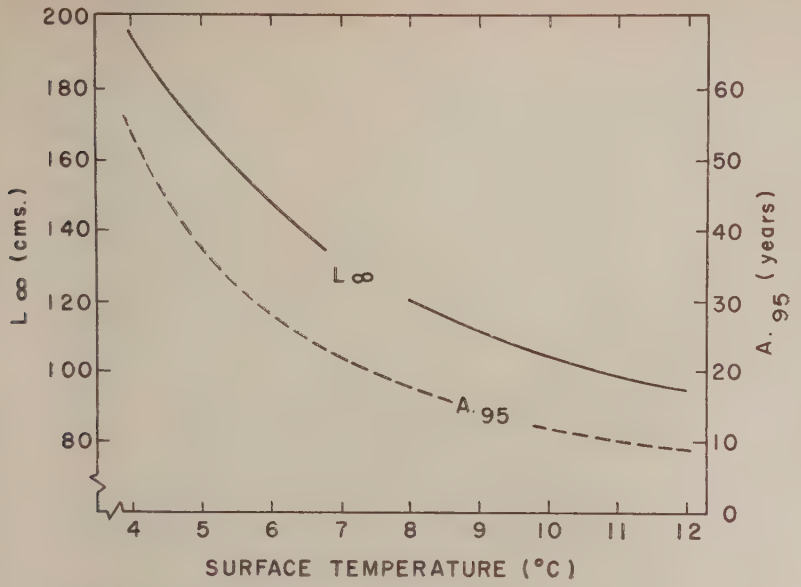

Figure 3. Calculated changes in maximum size (L_∞) and in life span ($A_{.95}$) with surface temperature.

Table 2

Relation of surface temperature on maximum size (L_∞) and life span ($A_{.95}$), as estimated by growth equations (7), (8), and (3), (4), (6)

	Surface temperature, °C.								
	4	5	6	7	8	9	10	11	12
L_∞ (cm.).....	196	167	148	132	121	113	105	100	95
$A_{.95}$ (yrs.)	56	38	29	22	18	15	12	11	9

to the effects of fishing. In some instances, at least, equations (7) and (8) suggest we may overestimate the influence of man and underestimate the influence of subtly-expressed but powerful forces at work in nature.

It must be pointed out that major changes in the thermal environment are known to have occurred in northern latitudes in recent times (Ahlmann *et al.*, 1949; Taylor, Bigelow and Graham, 1957). Possibly these changes may have been of sufficient duration and of sufficient magnitude to account for some of the observed changes in the size and age composition of cod populations in certain localities.

Summary

A linear relation between the logarithm of surface temperature and two growth parameters is demonstrated to hold for cod from certain areas ranging from Nantucket Shoals, off the north-east coast of the United States, to Norway and the North Sea. These relations suggest that the parameter K (equation 1)

and i (equation 2) are functions of the environmental temperature of the cod (indicated roughly by the surface temperature). If this is true, it is shown that the maximum size attained (L_∞) and the life span will be considerably affected by slight changes in temperature (Table 2, Figure 3). It is suggested that if such temperature-dependent changes should occur, they might be mistakenly interpreted as effects of fishing.

References

AHLMANN, H. W., *et al.*, 1949. "Climatic changes in the Arctic in relation to plants and animals." Cons. Int. Explor. Mer, Rapp. et Proc.-Verb., **125**: 1–52.

VON BERTALANFFY, L., 1938. "A quantitative theory of organic growth." Hum. Biol., **10**: 181–213.

BEVERTON, R. J. H., & HOLT, S. J., 1957. "On the dynamics of exploited fish populations". MAFF, Ser. 2, **19.**

GRAHAM, M., 1934. "Report on the North Sea cod." Fish. Invest. Lond., Ser. 2, **13** (4).

Hydrographic Office of the US Navy, 1944. "World Atlas of sea surface temperatures."2. ed., H. O. Publ., 225. Washington, 1954.

JENSEN, A. S., & HANSEN, P. M., 1931. "Investigations on the Greenland cod (*Gadus callarias* L.) with an introduction on the history of the Greenland cod fishery." Cons. Int. Explor. Mer, Rapp. et Proc.-Verb., **72** (1).

MARTIN, W. R., 1953. "Vital statistics of the cod and haddock in Subarea 4." ICNAF, 3rd Ann. Meet., Doc. 39.

ROLLEFSEN, G., 1934. "The cod otolith as a guide to race, sexual development and mortality." Cons. Int. Explor. Mer, Rapp. et Proc.-Verb., **88** (2).

SÆMUNDSSON, B., 1923. "On the age and growth of the cod (*Gadus callarias* L.) in Iceland waters." Medd. Komm. Danmarks Fisk.- og Havunders., Ser. Fisk., **7** (3).

TAYLOR, C. C., BIGELOW, H. B., & GRAHAM, H. W., 1957. "Climatic trends and the distribution of marine animals in New England." Fish. Bull. US Fish & Wildl. Serv., **57**: 293–345.

TAYLOR, C. C. (in press). "A note on Lee's phenomenon in the Georges Bank haddock." ICNAF Comm. Res. Statist., Rep. 1956 Interim Sess., Biarritz, France, March 1–10.

TROUT, G. C., 1954. "Otolith growth of Barents Sea cod." Cons. Int. Explor. Mer, Rapp. et Proc.-Verb., **136**: 89–102.

WALFORD, L. A., 1946. "A new graphic method of describing the growth of animals." Biol. Bull, **90** (2): 141–47.

On the Occurrence and Distribution of Larval Herring (*Clupea harengus* L.) in the Bay of Fundy and the Gulf of Maine[1,2]

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ABSTRACT

A major portion of the Bay of Fundy and Gulf of Maine has been surveyed for occurrence and distribution of herring larvae. Plankton samples obtained with Hardy continuous plankton recorders and plankton nets confirm major spawning areas off the southwest coast of Nova Scotia and on the northern edge of Georges Bank. Newly hatched larvae were found in abundance in these areas, but nowhere else. Drift of larvae as indicated by non-tidal surface currents suggests that Nova Scotia spawnings may contribute substantially to commercial stocks of herring in inshore areas of Maine and New Brunswick. It is possible that Georges Bank spawnings also supply herring to this region.

INTRODUCTION

Canada and the United States have a common interest in a fishery for young herring that are found in vast numbers in inshore waters of Charlotte County, New Brunswick, and along the Maine coast. Average annual landings approximate 200 million pounds and provide raw material for "sardine" canneries, pet food, and reduction plants.

There has been no recent evidence of major spawnings within the principal coastal "sardine" areas; in fact during the past 10 years only small quantities of adult herring have been caught there. About 1875, when the "sardine" industry started to become important, the fishery for adult herring in the area began to decline, and this trend has continued (Huntsman, 1953). Spawnings at Grand Manan, New Brunswick, and along the Maine coast were very extensive at one time (Earle, 1887) and still occur fairly regularly but are of only minor importance. Where then are the breeding grounds and the nursery areas for the fish that populate the region? What is the survival, growth, and dispersal of larvae and how are they transported?

To answer these questions, the Fisheries Research Board of Canada and the United States Fish and Wildlife Service began, in 1956, a co-operative investigation of the offshore areas of the Bay of Fundy and the Gulf of Maine.

[1]Received for publication July 3, 1958.

[2]This paper is based on investigations carried on jointly by the Fisheries Research Board of Canada and the U.S. Fish and Wildlife Service.

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Printed in Canada.

The main part of the program was carried on from September through February in 1956–57 and 1957–58. Additional data were available from *Prince* station tows taken monthly in the Passamaquoddy region and from cruises made by the M. V. *T. N. Gill* from May 1955 to January 1956. In March 1958, cruises with the M. V. *Mallotus* were carried out in the Grand Manan area at the entrance to the Bay of Fundy, and in St. Mary Bay, Nova Scotia.

Autumn and winter months were selected for the co-operative cruises because of known spawnings in southwestern Nova Scotia and on Georges Bank in August and September. Surveys were designed to study the abundance, size and distribution of the larvae that resulted from these spawnings.

Although the problem of the origin of the "sardine" herring in southern New Brunswick and Maine remains unsolved, some progress has been made and the discoveries to date are recorded in the following preliminary report.

MATERIALS AND METHODS

Canadian vessels used were M. V. *Harengus* (Fig. 1), C. N. A. V. *Fort Frances*, M. B. *Mallotus*, and M. V. *J. J. Cowie*. United States Fish and Wildlife Service supplied the M. V. *Silver Bay* (Fig. 1), M. V. *Albatross III*, M. V. *Delaware*, and M. V. *T. N. Gill*. In the initial planning, a series of cruise lines and stations was established (Fig. 2) which were followed as closely as possible throughout the investigation. The total length of the cruise lines was approximately 2,550 miles. Hardy continuous plankton recorders were towed throughout the cruises. Recorders had an aperture ¾ inch. (19 mm.) square and propeller angle setting of 70°. This propeller setting usually provided a 2-inch (51 mm.) section of gauze for each 5 miles (8 km.) of cruising. Canadian vessels towed one recorder at a depth of 10 metres. United States vessels used 2 recorders—one at the surface and one at 10 metres.

Additional plankton collections were made with silk or nylon 1-metre plankton nets of #0 mesh (12–15 threads per cm.). Nets were towed for 15 minutes at each station at approximately 3 knots. Two kinds of 3-level tows were made. One was at 0, 5, and 10 metres and the other was at 0, 10, and 20 metres. Tows in the September 1956 to February 1957 cruises were of the first type; in the September to November 1957 cruises of the *Harengus*, the second type was used. United States vessels made plankton tows every 4 hours and Canadian vessels towed at 95 established stations that were about 4 hours steaming-time apart.

Herring larvae were removed from the recorder gauzes and plankton collections. In tows that contained more than 100 larvae, a sample of 100 was taken for length measurements, otherwise all larvae were measured. Two length measurements were used, viz., *total length* from tip of lower jaw to longer lobe of caudal fin and *standard length* from tip of lower jaw to caudal peduncle. For this report, standard lengths of larvae 12 mm. and larger were converted to total lengths by use of the formula:

$$Y\,(\text{total length}) = 1.181X(\text{standard length}) - 2.0$$

Below 12 mm. the two lengths are identical.

FIG. 1. Two of the vessels used for the plankton cruises (upper) Canadian research vessel M. V. *Harengus*, (lower) United States chartered vessel M. V. *Silver Bay*.

Occurrence of herring larvae at two plankton stations in the Passamaquoddy region, *Prince* 5 (Lat. 44° 57′ 10″ N, Long. 66° 51′ 00″ W) and *Prince* 6 (Lat. 45° 04′ 54″ N. Long. 67° 06′ 07″ W) was recorded. These stations have been occupied monthly for more than 20 years by the Fisheries Research Board of Canada's St. Andrews Biological Station, giving 901 *Prince* Station collections, covering the years 1942 to 1958 (March) for *Prince* 5 and 1946 to 1958 (March) for *Prince* 6. Routine at *Prince* stations included vertical tows from 90 to 0 metres, and 15-minute oblique tows, one from 23 to 18 metres and the other from 7 to 5 metres. All tows were made with a 1-metre #0 plankton net.

From May 1955 to January 1956, 10 plankton cruises using the United States research vessel *T. N. Gill* were made chiefly in coastal waters of the Gulf of

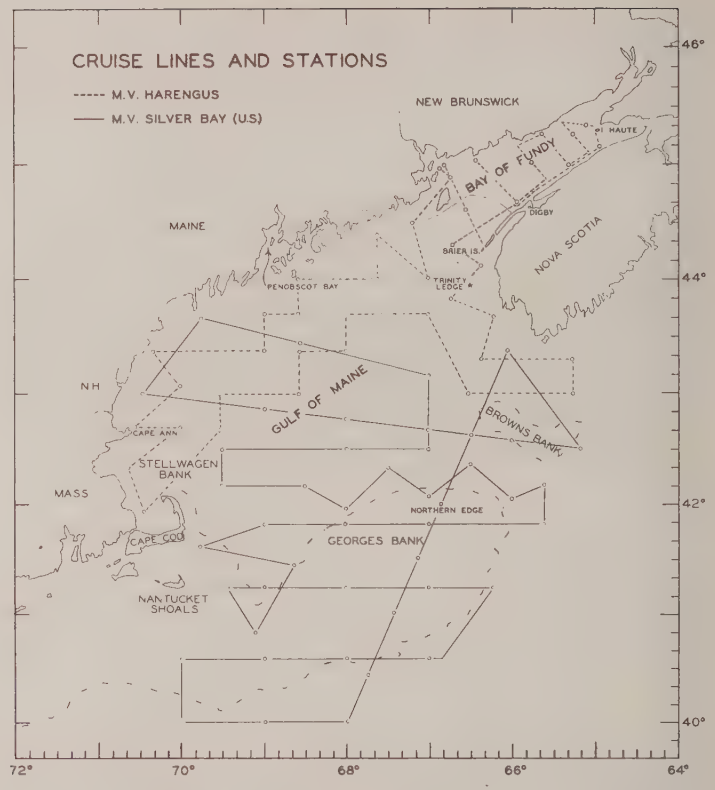

FIG. 2. Cruise lines and stations occupied during the September to February cruises 1956–57 and 1957–58.

Maine. A total of 191 plankton tows was taken with a 1-metre net towed for 15 minutes at 0, 5, and 10 metres (5 minutes at each depth). Data on larvae taken are included in this report.

During most cruises, bathythermograph casts, drift bottle releases, and air and surface water temperature observations were taken.

ABUNDANCE OF HERRING LARVAE

The total number of herring larvae examined was 50,037. The numbers of larvae taken, the gear used, the numbers of 1-metre net tows made, and the distances Hardy recorders were towed are listed in Table I. There were 30 larvae taken at *Prince* stations and 353 during *T. N. Gill* cruises. The majority of larvae, however, were taken in the joint cruises from September to February 1956–57 and 1957–58. Except for December 1956, when additional tows were made in areas where larvae were known to be abundant, largest numbers were taken in September and October of each year (Table I). The catch decreased sharply

TABLE I. Herring larvae caught in different years.

Date	Vessel or Station	1-metre net Larvae	1-metre net Tows	Hardy recorder Larvae	Hardy recorder Miles towed
		no.	*no.*	*no.*	*no.*
1942-1957	*Prince* Station 5	23	487	...	...
1946-1957	*Prince* Station 6	7	414	...	...
1955-1956	*T. N. Gill*	325	191	28	3,051
Sept. 1956	*Silver Bay, Harengus*	5,619	101	23	2,619
Oct. 1956	*Silver Bay, Harengus*	6,453	96	52	2,788
Nov. 1956	*Silver Bay, Harengus*	1,635	100	37	2,768
Dec. 1956	*Silver Bay*	18,319	109	...	...
Jan. 1957	*Delaware*	196	51	9	1,842
Feb. 1957	*Albatross III*	259	97	18	1,550
Sept. 1957	*Harengus*	4,187	53	0	1,345
Oct. 1957	*Harengus*	12,017	70	1	615
Nov. 1957	*Harengus*	347	48	11	510
Dec. 1957	*Albatross III, Delaware*	271	76	34	2,347
Jan. 1958	*Albatross III, Delaware*	93	62	23	1,804
Feb. 1958	*Fort Francis*	46	67	4	1,795
	Total	49,797	2,022	240	23,034

in November and was very light in January and February. Additional tows in December 1956 were made to investigate depth distribution of larvae and these account, in part, for the large number (18,319) taken during that month.

No attempt has been made here to compare abundance of larvae for the two seasons 1956–57 and 1957–58 because of variations in numbers of tows and in localities where tows were made. In both seasons, large numbers of larvae were taken in a few tows and a comparison of average numbers per tow would have little meaning. Only 240 larvae were taken with plankton recorders, in contrast to 49,797 in 1-metre nets.

DISTRIBUTION OF HERRING LARVAE

Catches indicate that during September larvae are not widely dispersed in the Gulf of Maine. In September 1956 (Fig. 3A) large concentrations were found on Georges Bank. Small numbers were found around Nantucket Shoals off Massachusetts and near Ile Haute and Brier Island in the Bay of Fundy. A few individuals were taken off the coast of Maine. In September 1957 (Fig. 3B) cruises covered only the Bay of Fundy, the coast of Maine and the northern edge of Georges Bank. The only herring larvae captured were in the Bay of Fundy and along the southwest coast of Nova Scotia. A major concentration occurred near Brier Island. Absence of larvae on Georges Bank suggests that herring in the area had not spawned, or eggs had not yet hatched.

In October, larvae were more widely distributed. In October 1956 (Fig. 3C), larvae occurred throughout most of the Georges Bank area with major concentrations on the northern edge. Both Hardy recorder and plankton net samples caught larvae in the southern portion of Georges Bank. Scattered larvae were

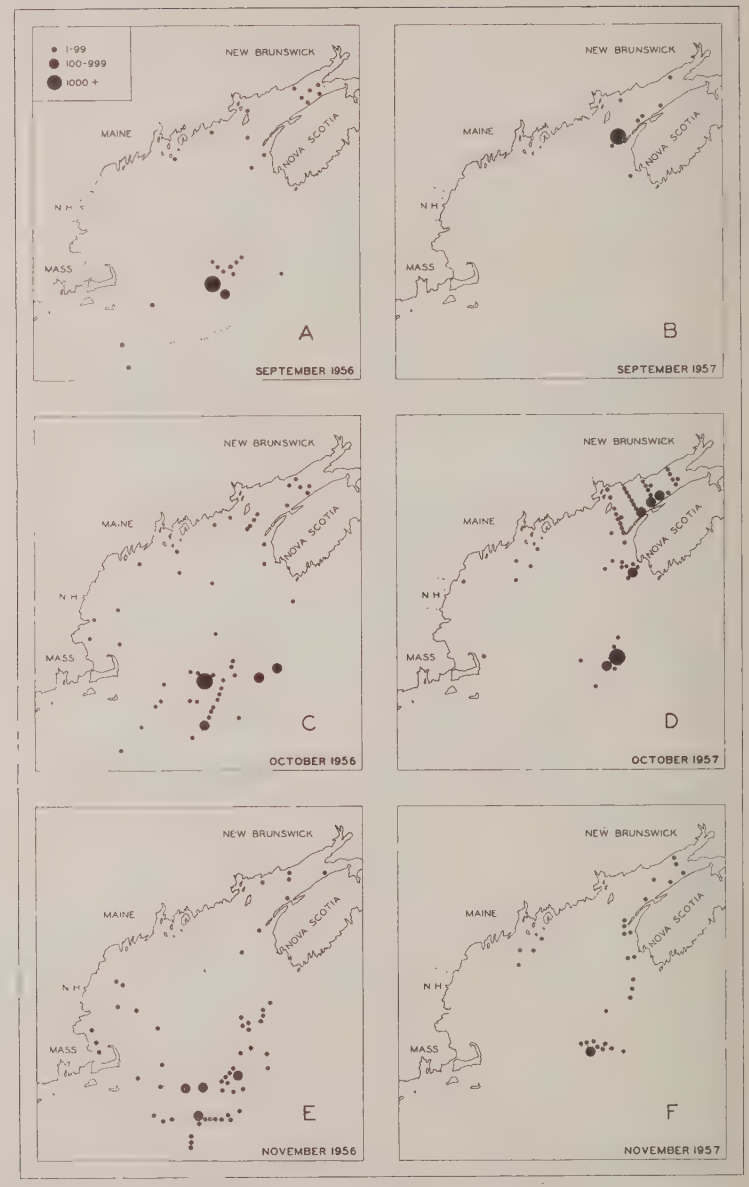

FIG. 3. Distribution of herring larvae September to November 1956 and 1957.

taken in the Bay of Fundy. A few were found around Stellwagen Bank and offshore from Penobscot Bay. In October 1957 (Fig. 3D), large numbers were taken on the northern edge of Georges Bank and near Trinity Ledges at the southern tip of Nova Scotia. Larvae were taken in 29 out of 33 tows in the Bay of Fundy. They were well dispersed throughout the Bay with largest concentrations near Digby. Some larvae were taken offshore in the vicinity of Penobscot Bay and off Cape Cod.

Larvae in November 1956 (Fig. 3E) were more widely dispersed than for most months during the survey. They were heavily concentrated on Georges Bank but, in general, were farther south than in September and October. Concentrations on the northern edge of Georges Bank in September and October appear to have been broken up with some larvae having moved northeast over Browns Bank, while the majority had moved south on Georges Bank. Only a few larvae were caught in the Bay of Fundy, along the Maine coast, on Stellwagen Bank and in the middle of the Gulf of Maine. In November 1957 (Fig. 3F), larvae were again concentrated heavily on the northern edge of Georges Bank. As in November 1956, some dispersal of larvae northward toward the Nova Scotia coast was evident, while in the Bay of Fundy major concentrations were no longer evident, and small concentrations were found in the northern part of the Bay and along the west coast of Nova Scotia. Along the Maine coast, a few larvae were taken offshore in the vicinity of Penobscot Bay.

In December 1956 (Fig. 4A), sampling was restricted to Georges Bank and inshore areas of Maine and New Hampshire. Heavy concentrations of larvae were found on the southern half of Georges Bank and smaller concentrations on Stellwagen Bank. In December 1957 (Fig. 4B), larvae from 1-metre net catches were scarce over Georges Bank and in the Bay of Fundy. The heavy concentrations of September, October, and November now showed a more widely dispersed pattern of distribution.

In January 1957 and 1958 (Fig. 4C, and D), distributions were similar for the Gulf of Maine and Georges Bank. There was no cruise in the Bay of Fundy in January 1957. In January 1958, small concentrations of larvae were found at more than half (12 out of 22) of the stations occupied.

In February 1957, sampling was restricted to inshore areas of the Gulf of Maine and the Bay of Fundy and a wide distribution of larvae was observed as shown in Fig. 4E. In February 1958 (Fig. 4F), only small numbers were taken anywhere, most of them on or immediately north of Georges Bank.

Differences between catches in January and February of both years were chiefly in numbers taken rather than distribution. It is likely that by January the larvae were large enough to avoid the plankton nets.

Distribution and numbers of larvae taken during *T. N. Gill* cruises are shown in Fig. 5. In April, 17 larvae were caught west of Penobscot Bay, Maine. In June and July, no larvae were taken. In August, 18 newly hatched larvae were taken in one tow on Trinity Ledges. In October no larvae were taken in a cruise from Penobscot Bay to Cape Ann. A November cruise in the Gulf of Maine, on Georges Bank, and in the Bay of Fundy took 51 larvae on Georges and

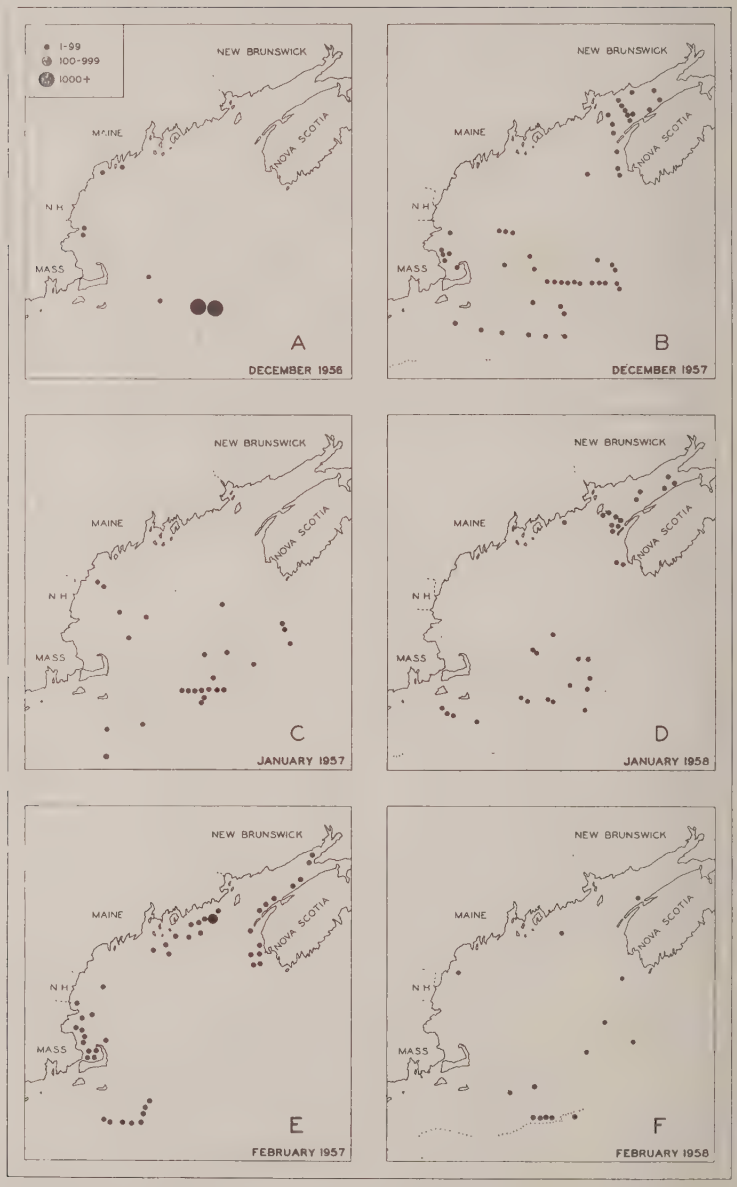

FIG. 4. Distribution of herring larvae December to February 1956–57 and 1957–58.

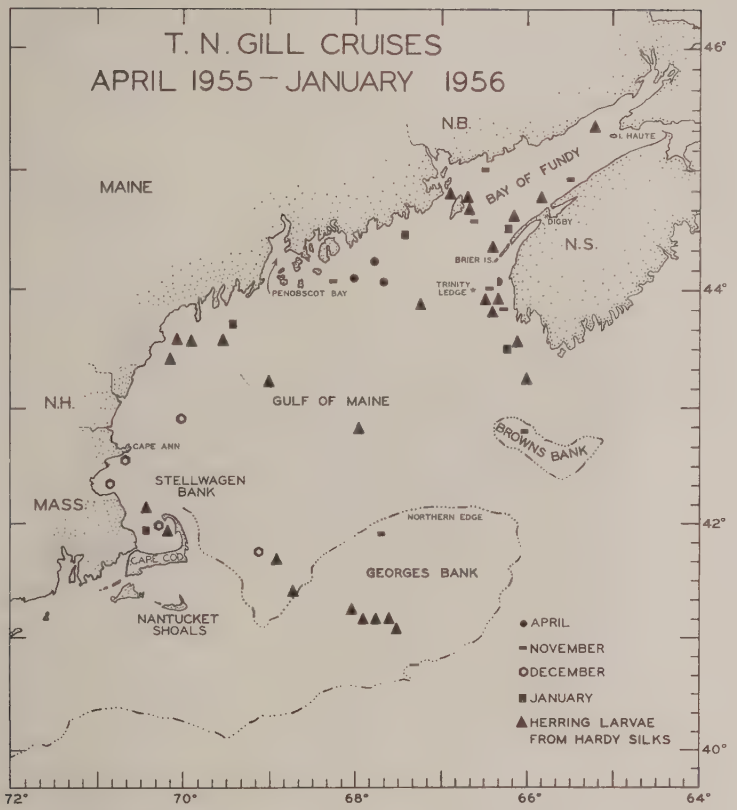

FIG. 5. Distribution of herring larvae caught during the *T. N. Gill* cruises April 1955 to January 1956.

Browns Banks, on Trinity Ledges, in the Bay of Fundy, and around Penobscot Bay. In December, a short cruise was made along the New England coast during which 187 larvae were taken. Fifty-two herring larvae were taken during a January cruise along the western coast of Nova Scotia, the coast of Maine, and around Cape Cod. Distribution of 28 larvae taken with plankton recorders during *T. N. Gill* cruises was similar to that for the 1-metre net hauls.

LENGTH COMPOSITION

Size compositions of larvae by months are given in Table II, and Fig. 6 and 7. For Fig. 6, an arbitrary division of the larvae into small (4–9 mm.), medium (10–19 mm.) and large (20–50 mm.) size groups has been made.

In September 1956, 69.1% of the larvae taken were in the small, 30.3% in the medium, and 0.6% in the large size-categories. In September 1957, 96.0% of the larvae were small and the remaining 4.0% of medium size. In October 1956, there

TABLE II. Length frequencies of herring larvae taken in the Bay of Fundy and Gulf of Maine.

	1956				1957						1958	
Length	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
mm.	*no.*	*no.*	*no.*	*no.*	*no.*	*no.*	*no.*	*no.*	*no.*	*no.*	*no.*	*no.*
4	0	...	...	...	...	...	5	2	...	...	...	...
5	14	5	...	...	...	...	29	56	...	...	...	...
6	64	48	...	...	...	...	53	96	...	2	...	...
7	41	86	...	...	...	...	64	144	4	1	...	...
8	43	99	...	...	...	...	29	100	89	1	...	...
9	59	71	...	...	...	...	9	69	32	0	...	...
10	44	37	5	...	...	...	1	48	3	2	...	...
11	15	27	8	...	...	...	1	35	2	6	...	...
12	11	23	18	...	...	...	1	98	14	5	...	...
13	6	17	20	2	...	...	0	126	18	12	...	...
14	3	19	22	10	...	...	0	155	8	12	...	...
15	11	16	28	42	...	...	1	181	13	12	2	...
16	2	15	32	102	...	...	2	86	23	12	2	...
17	1	9	32	197	...	...	0	38	29	12	1	...
18	2	5	35	326	...	...	1	34	30	9	0	...
19	2	5	26	396	...	...	1	22	25	16	0	...
20	0	1	18	421	...	...	...	25	12	16	0	...
21	2	7	24	428	...	...	...	25	13	17	4	1
22	...	3	21	391	1	1	...	23	16	13	4	0
23	...	4	17	173	1	1	...	14	4	13	3	3
24	...	5	22	110	2	0	...	8	4	18	4	2
25	...	9	29	78	2	0	...	12	3	14	4	2
26	...	2	25	70	3	0	...	8	1	12	3	4
27	...	0	31	95	4	5	...	7	0	8	6	2
28	...	1	29	93	7	5	...	4	1	7	4	3
29	...	...	21	129	9	5	...	7	0	8	6	5
30	...	...	18	125	9	4	...	8	1	8	10	5
31	...	...	8	49	8	2	...	3	...	6	10	2
32	...	...	8	26	10	3	...	5	...	3	7	3
33	...	...	5	11	9	6	...	0	...	3	5	2
34	...	...	7	7	9	7	...	1	...	3	4	1
35	...	...	3	4	9	7	...	1	...	1	4	1
36	...	...	0	2	11	8	...	1	...	0	4	3
37	...	...	0	0	14	9	...	0	...	1	1	0
38	...	...	0	1	14	13	...	0	...	1	1	1
39	...	...	0	...	14	16	...	0	...	...	2	2
40	...	...	1	...	20	19	...	1	...	...	...	1
41	...	...	1	...	15	20	...	...	...	...	...	1
42	...	...	1	...	7	24	...	...	...	...	...	0
43	...	...	...	...	1	23	...	...	...	...	...	0
44	...	...	...	...	1	16	...	...	...	...	...	0
45	...	...	...	...	0	14	...	...	...	...	...	0
46	...	...	...	...	1	3	...	...	...	...	...	0
47	...	...	...	...	0	2	...	...	...	...	...	0
48	...	...	...	...	1	1	...	...	...	...	...	1
49	...	...	...	...	1	...	...	...	...	...	...	0
50	...	...	...	...	...	...	...	...	...	...	...	1
Totals	320	514	515	3,198	183	214	197	1,443	345	254	91	46

were still large numbers of small larvae (60.1%) but in October 1957, the numbers of small larvae had fallen off considerably from the previous month and represented 32.2% of the total catch. The majority of the larvae (57.0%) taken in October 1957 were in the medium size group. No small herring larvae were taken after October in 1956 but in 1957, 32.2% of the November catches and 1.6% of the December catches were small. This tends to confirm a later spawning on

Georges Bank in 1957 than in the previous year. For both seasons January and February samples contained no newly hatched larvae but for these months in 1958 there were more of the medium size group than during the same period in 1957.

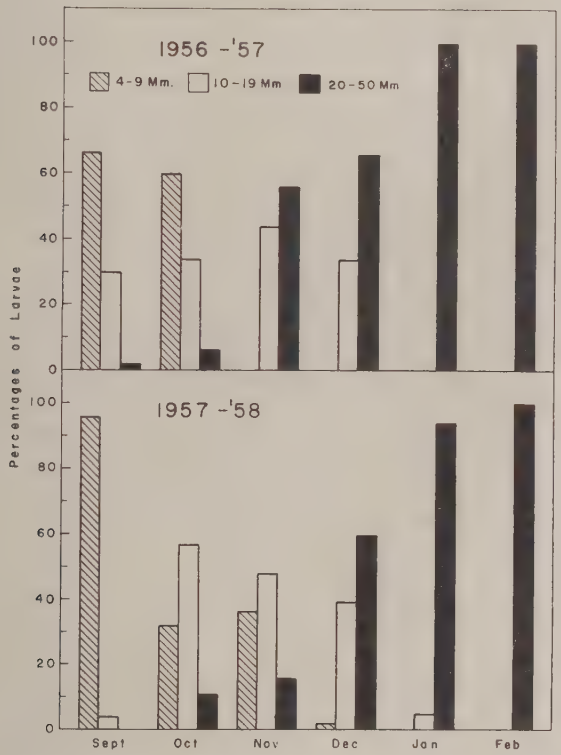

FIG. 6. Variations in the relative abundance of small, medium and large herring larvae during the autumn and winter months.

Length frequency distributions for the two seasons (Table II, Fig. 7) show bi-modality particularly for November and December 1956 and for February, October, and December 1957. The general pattern of larval growth is seen in the shift of histograms to the right as the seasons progress (Fig. 7). In September samples, the range of larval lengths is quite small, and the population appears to be homogeneous (Table II). As the season advances, larvae from other spawnings are added to existing populations, and the size range increases. This may be due to a mixture of larvae from separate populations, but is more likely the result of separate spawnings that occur progressively later within the same parent population.

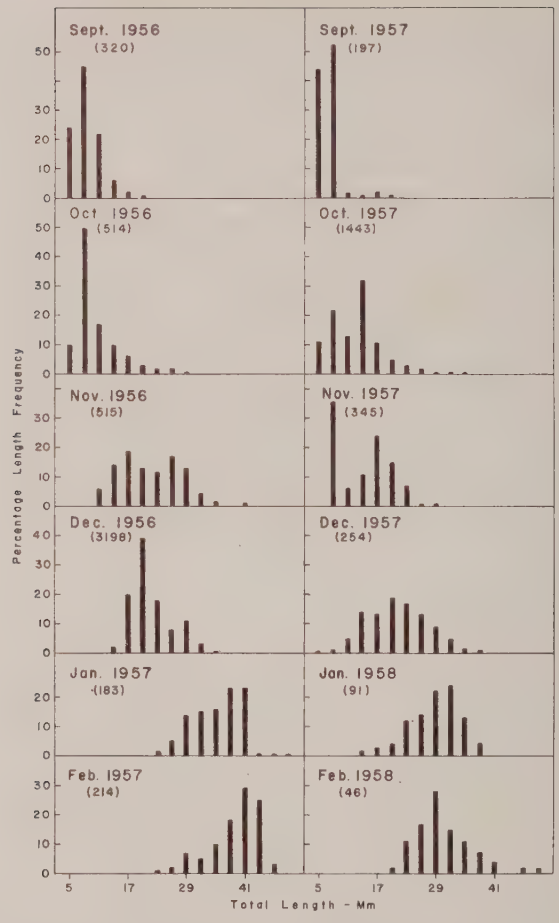

FIG. 7. Length frequency distributions of herring larvae September to February 1956–57 and 1957–58. Data are combined in 3 mm. size groups.

RATE OF GROWTH

An approximate measure of growth can be obtained by plotting mean lengths of larvae taken during each month (Fig. 8). Bowers (1952) presented a growth curve for autumn-spawned herring larvae on the Manx coast off northwestern England. In this area, hatching takes place in October and November. By November surface water temperatures have decreased to about 10°C. from 15°C. in August. Bowers' growth curve was drawn from modal rather than mean lengths.

On Georges Bank, where the majority of larvae were taken, mean monthly surface temperatures varied from 14.1°C. in September 1956, to 9.8°C. in December 1957 (Table III). November temperatures averaged 11.9°C. or nearly 2°C.

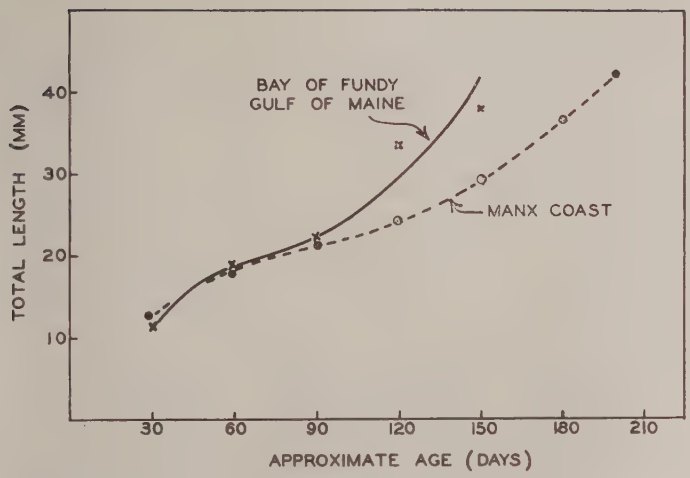

FIG. 8. Growth rates of herring larvae (data for Manx coast from Bowers, 1952).

TABLE III. Mean water temperatures (degrees Centigrade) recorded by bathythermograph on Georges Bank. Numbers of monthly observations are in parentheses.

	1956				1957		1958
Depth	Sept. (28)	Oct. (25)	Nov. (29)	Dec. (7)	Jan. (23)	Dec. (21)	Jan. (21)
feet	°C.	°C.	°C.	°C.	°C.	°C.	°C.
Surface	14.1	13.9	11.9	10.7	5.7	9.8	7.9
30	13.0	13.8	11.8	10.7	5.7	9.7	7.9
50	12.9	13.7	11.8	10.7	5.7	9.7	7.9
100	12.4	13.6	11.9	10.7	5.7	9.8	7.9
150	13.1	13.3	10.8	...	5.7	9.9	8.1

higher than off the Manx coast. Hatching on Georges Bank takes place from September to November in some seasons.

Figure 8 shows a striking similarity between growth curves for the Bay of Fundy–Gulf of Maine and the Manx areas for the first 3 months (90 days). Subsequently, growth rate is more rapid in the Bay of Funday–Gulf of Maine area than on the Manx coast. This may be accounted for by higher surface water temperatures on Georges Bank. Supporting evidence for substantial growth in January and February (estimated 120 and 150 days after hatching) is available from studies of the scales of 1- and 2-year-old herring from the Bay of Fundy and the Gulf of Maine areas. Examinations of scales show that new annual growth zones on the scales of "sardine" herring are apparent in January (unpublished data).

DAY AND NIGHT CATCHES OF HERRING LARVAE

Day and night catches for the September to February cruises are given in Table IV. Division between day and night was made on a 12-hour basis with the dividing points at 6 a.m. and 6 p.m. There were 930 tows taken, 493 during the day and 437 at night.

Total catches for both seasons show that 27.2% of the larvae were taken during the day and 72.8% during the night. Calculated on the basis of average catch per tow, 24.9% were caught during the day and 75.1% at night.

TABLE IV. Day and night catches of herring larvae, by months.

Period	Day		Night		Total
	no.	%	*no.*	%	*no.*
Sept. 1956	4,555	81.0	1,064	19.0	5,619
Oct. 1956	5,909	91.6	544	8.4	6,453
Nov. 1956	25	1.5	1,610	98.5	1,635
Dec. 1956	2,245	12.3	16,074	87.7	18,319
Jan. 1957	1	0.5	195	99.5	196
Feb. 1957	18	6.3	241	93.7	259
Total	12,753	39.3	19,728	60.7	32,481
Sept. 1957	72	1.7	4,115	98.3	4,187
Oct. 1957	570	4.7	11,447	95.3	12,017
Nov. 1957	23	6.6	324	93.4	347
Dec. 1957	60	22.1	211	77.9	271
Jan. 1958	4	4.3	89	95.7	93
Feb. 1958	7	15.2	39	84.8	46
Total	736	4.3	16,225	95.7	16,961
Grand total	13,489	27.2	35,953	72.8	49,442

Catches were made chiefly at night except on September 25 and on October 22 when 4,522 and 5,726 larvae respectively were taken in the late afternoon.

Differences between day and night catches were particularly evident in January and February collections when from 84.8 to 99.5% of the larvae were caught at night. During these months 529 of the 534 larvae caught were more than 19 mm. long (mean lengths 33.2 to 37.6 mm.). At these sizes larvae may be expected to avoid a plankton net particularly during daylight hours.

These results are in agreement with those of Bridger (1956) who found a similar relationship between day and night catches of herring larvae.

SPAWNING AREAS AND SEASONS

From sizes and abundance of larvae taken, spawning areas have been determined (Fig. 9). Jean (1956) reported larvae as small as 4 mm. in the Gulf of St. Lawrence. In northern Scotland, herring larvae hatch at 6 to 8 mm. (Fage, 1920). Bower (1952) reported that newly hatched larvae in Manx waters vary from 6 to 9 mm. in length.

In determining the spawning grounds in the Gulf of Maine and the Bay of Fundy, larvae from 4 to 9 mm. in total length were considered newly hatched

and not far removed from the spawning areas. In a few instances, chiefly in southwest Nova Scotia, direct evidence of spawning is available from collections of eggs but, in general, newly hatched larvae have been used as indicators of spawning grounds.

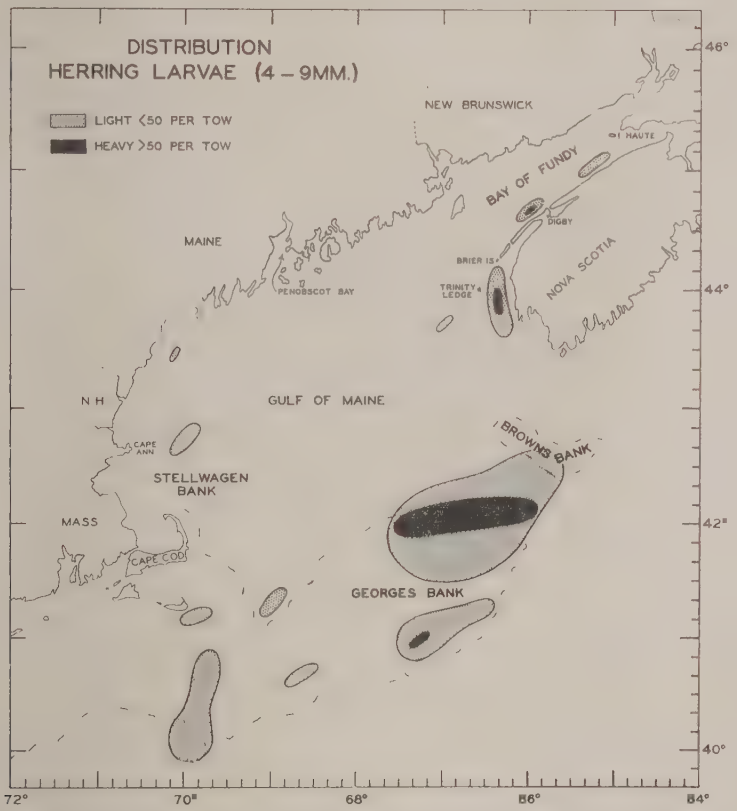

Fig. 9. Herring spawning areas in the Bay of Fundy and the Gulf of Maine estimated from the distribution of newly hatched (4-9 mm.) larvae.

Areas

The largest spawning area in the Gulf of Maine is on the northern edge of Georges Bank (Fig. 9). This is a shoal area, varying in depth from 3½ fathoms to 50 fathoms. It is characterized by strong tidal currents and heavy mixing. The bottom varies from a granular boulder type to a fine sandy type (Wigley, 1956). Newly hatched herring larvae were found in very large numbers in this area and as many as 5,726 have been taken in a single, 15-minute plankton tow.

Fig. 9 also shows that herring spawn in the Bay of Fundy from the Seal Island group northward along the Nova Scotia coast to Digby. Another spawning area lies just north of Digby and could, presumably, be an extension of the

first area. Depths vary from 3 to 50 fathoms. Temperatures are fairly uniform from top to bottom due to strong tidal mixing. Character of the bottom has not been described.

Other spawning areas are not very extensive, but may contribute to the stocks of herring in the region. Although very few larvae were taken, there is evidence of small spawnings around Penobscot Bay, Stellwagen Bank, and Nantucket shoals. Moore (1898), Huntsman (1919) and Bigelow and Schroeder (1953) reported an important spawning in the waters south of Grand Manan. Leim (1958) reported the presence of recently hatched larvae in the southern Grand Manan area seasonally from 1917 to 1955. It is evident that spawnings occur regularly in this area but not to the same extent as in southwestern Nova Scotia and on Georges Bank.

Spring Spawning

McNairn (1933) reported small spring spawnings at the heads of the Bay of Fundy and St. Mary Bay. Fish and Johnson (1937) also reported spring spawnings in the Fundy region. Bigelow and Schroeder (1953) reported a few instances of spring spawning in the inshore waters of Nova Scotia and New Brunswick. Mr. E. G. Sollows (personal communication) found some larvae in May near Tucket Island and in St. Mary Bay that were almost certainly spawned in the spring. Mr. John B. Colton, Jr. (unpublished data) caught a few small larvae (9–10 mm.) on Georges Bank and along the coast of Maine during the spring of 1955 and 1956. Six spring-spawned larvae were taken in the Passamaquoddy region in *Prince* tows (unpublished data).

There were few instances of spring-spawned larvae being taken during the course of this investigation. In March 1958, a cruise covering the Grand Manan area, the entrance to the Bay of Fundy and St. Mary Bay showed no newly hatched larvae. A few of the large larvae caught in September and October 1956 and 1957 may have been spawned in late spring or early summer.

It is evident that, for the Gulf of Maine and the Bay of Fundy region, spring spawning is very light and very much less in importance than the heavy autumn spawning. Graham (1936) also found that "spring spawning produced no considerable contributions to the herring stock [in the Bay of Fundy area]."

Autumn Spawning

Most Fundy herring spawn in summer or autumn (McNairn, 1933). Fish and Johnson (1937) found that herring spawn in the Gulf of Maine in summer and autumn but in the Fundy region both spring and autumn spawning takes place. Bigelow and Schroeder (1953) reported heavy spawnings southwest of Grand Manan, around the Trinity Ledges off southwestern Nova Scotia, and light irregular spawnings along the Maine coast.

Heavy spawnings occurred on Georges Bank and along southwestern Nova Scotia from August to October in 1956 and 1957. There was no evidence of spawning in November and December of 1956, but there were signs of a light spawning in November and December, 1957. Whiting fishermen report that

"mature herring arrive on Georges Bank in August and hang just off the northern edge until conditions are right, then, moving into the shoal areas, they spawn."

It is possible to establish a general pattern of movements of herring larvae from spawning grounds on the basis of known non-tidal surface currents. Day (1957) found that current patterns on Georges Bank shift with seasons and prevailing winds. Assuming that currents are important means of distributing larvae, we can speculate on their movements. On the basis of Day's current patterns the larvae spawned on the northern edge of Georges Bank would be swept across Browns Bank towards the southern coast of Nova Scotia. Larvae found elsewhere on Georges Bank would be swept southward. Nantucket shoals larvae would appear along Rhode Island and New Jersey while Stellwagen larvae would be swept southward along Cape Cod. In the Bay of Fundy, movement is somewhat more complex, but would be northward along the southwest coast of Nova Scotia and southward along the coast of New Brunswick and Maine. Eddies complicate this movement, but in general, it will be counter-clockwise.

SUMMARY AND CONCLUSIONS

1. Investigations to discover the breeding grounds, the nursery areas, the survival, growth and methods of transport of the larvae of herring that populate the Passamaquoddy region of New Brunswick and Maine were initiated jointly in 1956 by the Fisheries Research Board of Canada and the U.S. Fish and Wildlife Service.

2. Offshore cruises with plankton nets and Hardy continuous plankton recorders were carried out in the Bay of Fundy and Gulf of Maine from September through February in 1956–57 and 1957–58.

3. During the two seasons, 49,442 larvae were taken in 1-metre net hauls and 212 in recorders. In addition, 30 larvae were available for study from *Prince* station tows and 353 from *T. N. Gill* cruises.

4. Largest numbers of larvae were taken in September and October of each year. Catches decreased sharply in November and were very small in January and February.

5. Larvae were abundant only in the Bay of Fundy and on Georges Bank. Small numbers were taken occasionally throughout most of the survey area.

6. Newly hatched larvae (4 to 9 mm.) were found chiefly in September and October. In some seasons hatching may extend well into November and possibly into December. Growth is slow and larvae, presumably from September and October hatchings, are found in February.

7. Growth in the Bay of Fundy-Gulf of Maine area is faster than for the Manx area in the Irish Sea.

8. About 73% of all larvae in plankton nets were taken at night. The difference between day and night catches was more pronounced for large larvae (20 to 50 mm.).

9. The largest spawning area in the Gulf of Maine is on the northern edge of Georges Bank. Large spawnings occur off the Nova Scotia coast from Trinity

Ledges to Digby. Small spawnings occur in Penobscot Bay, on Stellwagen Bank, Nantucket shoals and south of Grand Manan.

10. Late summer and autumn spawnings are undoubtedly the major contributors to the herring stocks in the Bay of Fundy and Gulf of Maine. Spring spawnings are of only minor importance.

11. Larvae are found in the upper water layers and are probably carried from the spawning grounds by the non-tidal surface currents. Surface current patterns suggest that some larvae from Georges Bank spawnings are carried northward to Nova Scotia coast but the majority of them may be carried southward.

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REFERENCES

Bigelow, Henry B., and William C. Schroeder. 1953. Fishes of the Gulf of Maine. *U.S. Fish. and Wildlife Service, Fish. Bull.*, **53**(74): 577 pp.

Bowers, A. B. 1952. Studies on the herring (*Clupea harengus* L.) in the Manx waters:—the autumn spawning, and the larval and post-larval stages. Proc. Trans. Liverpool Biol. Soc., 58: 47–74.

Bridger, J. P. 1956. On day and night variation in catches of fish larvae. *J. Conseil Explor. Mer.*, **22**(1): 42–57.

Day, C. G. 1957. Drift bottle studies over the Gulf of Maine and Georges Banks. Woods Hole Oceanogr. Inst., Ref. No. 57–1, 17 pp. (Processed).

Earle, R. Edward. 1887. The herring fishery and the sardine industry. In: G. B. Goode, The Fisheries and Fishery Industries of the United States, Sec. 5, 1: 417–542.

Face, L. 1920. Engraulidae. Clupeidae. *Rept. Danish Oceanogr. Exped. Mediterranean and Adjacent Seas*, **2**, Biol. A9, pp. 1–40.

Fish, Charles J., and Martin W. Johnson. 1937. The biology of the zooplankton population in the Bay of Fundy and Gulf of Maine with special reference to production and distribution. *J. Biol. Bd. Canada*, **3**(2): 189–322.

Graham, Michael. 1936. Investigations of the herring of Passamaquoddy and adjacent regions. *J. Biol. Bd. Canada*, **2**(2): 95–140.

Huntsman, Archibald G. 1919. Growth of the young herring (so-called sardines) of the Bay of Fundy. *Ottawa, Dept. Naval Serv., Can. Fish. Exped.*, 1914–1915, pp. 165–171.

1953. Movements and decline of large Quoddy herring. *J. Fish. Res. Bd. Canada*, **10**(1): 1–8.

JEAN, YVES. 1956. A study of spring and fall spawning herring (*Clupea harengus* L.) at Grande-Rivière, Bay of Chaleur, Quebec. *Quebec Dept. Fish., Contrib.* No. 49, 76 pp.

LEIM, ALEXANDER H. MS, 1958. Distribution of herring larvae in the lower Bay of Fundy and adjacent waters. Fisheries Research Board of Canada, Biological Station, St. Andrews.

MACFARLAND, W. E. 1931. A study of the Bay of Fundy herring. *Biol. Bd. Canada, Ann. Rept.* for 1930, pp. 22–23.

MCNAIRN, N. A. 1933. Herring races of the Bay of Fundy. *Biol. Bd. Canada, Ann. Rept.*, for 1932, p. 29.

MOORE, H. F. 1898. Observations on the herring and herring fisheries of the northeast coast, with special reference to the vicinity of Passamaquoddy Bay. *U.S. Comm. Fish. and Fisheries, Rept.* for 1896, pp. 387–442.

WIGLEY, ROLAND L. 1957. Bottom ecology. *U.S. Fish and Wildlife Serv., Ann. Rept. Woods Hole Laboratory*, pp. 12–15.

Reprinted from THE JOURNAL OF PARASITOLOGY, February, 1958,
Vol. 44, No. 1, page 72.

LAPHYSTIUS STURIONIS PARASITIC ON COD IN NORTH AMERICAN WATERS.

On April 1, 1957, during a cruise of the Research Vessel *Albatross III* on the Northeast Peak of Georges Bank (41° 53′ N. Lat., 66° 14′ W. Long.) a cod was caught in about 45 fathoms. The fish had a sore on the proximal dorsal side of its left pectoral fin, about 4 cm in circumference and 1 or 2 mm deep. Perhaps a dozen small amphipods, roughly 2 to 4 mm in length, were moving about on the sore, apparently feeding. The cod appeared otherwise healthy and was tagged and released.

Three of the amphipods were preserved and later identified as *Laphystius* (=*Lafystius*) *sturionis* Kröyer. This species has been reported as parasitic on other fishes in New England waters (Rathbun, 1905, Occas. Papers Bost. Soc. Nat. Hist. **7:** 1–117; Holmes, 1905, Bull. Bur. Fish. **24:** 457–529) and as parasitic on cod in European waters (Dollfus, 1953, Encyclopédie Biologique **43:** 1–423). R. L. Wigley, who confirmed the identification, has found a single specimen free-living on Georges Bank. This, however, is believed to be the first record of the species parasitic on cod in the Northwest Atlantic (Specimens will be sent to U.S.N.M.) —JOHN P. WISE, *U. S. Fish and Wildlife Service, Woods Hole, Massachusetts.*

Many phases of ant life and societies discussed: castes and classes, the 's body and division of labor, sex, marriage flight, the building of colies and nests, aliens and enemies, fare and hunting, food and shelter, naries and fungus gardens, aphid ders, and ant plants. The author's p interest in and patient observation nts has led him to perform remarkable earch into ant trail making, recogon and communication among ants, rt signals, and their mental faculties. s interesting to note that the usual azonian ant society consists mainly females, including the winged egging queen, the workers, and the largeded soldiers, performing various ctions, whereas the winged males are siderably fewer in number, and have sole function of fertilization. The nor has been able to transform larvae workers or soldiers by feeding them tain foods.

The reader is introduced into a world nimals which have complex and fasating societies. The nature lover l find many of his questions about ubiquitous ant answered.

Sophy Parfin

ANKLIN D. ROOSEVELT AND CONSERVATION, 1911 - 1945. Compiled and Edited by Edgar B. Nixon. Government Printing Office. 1957. Vols. 2; pp. 614, 700. $9.50.

"I see an America whose rivers and leys and lakes — hills and streams l plains — the mountains over our land l nature's wealth deep under the earth — protected as the rightful heritage of the people."

These words of President Franklin D. osevelt at Cleveland, Ohio, on Noember 2, 1940, summarize the objectives the most eventful years in the convation history of our country. If we e not lived up to the intellectual herge of the Roosevelt years, it is because , as a people, have not yet learned t only a citizenry of convinced convationists can keep public officials l private interests dedicated to the l of protecting our natural resources. The two volumes of Roosevelt papers lude all of the basic and significant terials concerned with renewable reurces — soil and water, forests and wilderness, wildlife and recreational areas — and contained in the Franklin D. Roosevelt Library at Hyde Park.

A documentary story is necessarily sketchy and repetitive, and a chronological ordering imposed by the character of the materials does not facilitate quick topical reviews. The offsetting advantages lie in the identification of the actors in the conservation story, in the disclosure of how one issue reenforces or modifies another, and in a sense of the prevailing climates of opinion and of triumphs over real obstacles.

In bringing together the documentary record of F D R's role in the safeguarding of our renewable resources, from his first days on the Forest, Fish and Game Committee of the New York State Senate to his closing days as President, the Franklin D. Roosevelt Library has performed a useful service not only for research scholars but also for the citizen conservationists who wish to understand the background of today's conservation issues. Mr. Nixon's skillful editing and explanatory notes provide an indispensable guide to evaluating the documents in their historical settings. *I. R. Barnes*

Bertin, Leon. EELS: Philosophical Library. 1957. pp 192. Illus. $7.50.

EELS begins with an excellent historical review of knowledge of the biology and natural history of the eel from ancient times until the present, followed by a study of the classification of the eels of the world which points out their similarities and differences. Emphasis throughout is appropriately on the European eel; this is the species most utilized by mankind and the one on which most scientific studies have been conducted. Careful attention is paid to the physiology of the animal, with consideration of the most modern physiological concept.

Most of the volume is given over to systematic and logical consideration of the life history of the European eel, through the "yellow" eel of fresh water and its transition into the "silver" eel which emigrates to the sea, and the almost incredible return of the leptocephalus larva to the home continent of its parents. Proper credit is given for the years of collection and deduction

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devoted to this subject by Johannes Schmidt, to whom the book is dedicated. Other species of eels are considered in a final chapter and referred to throughout the text as examples.

The book has some faults, the major one perhaps being that it seems aimed at no particular audience. In some sections Professor Bertin discusses without explanation points which amateur naturalists may find highly technical, in others he digresses for several pages to elucidate points which are elementary to the professional, e.g., the concepts of normal statistical distribution and osmosis. The biologists who will use this volume as a standard reference will be hampered by the incomplete documentation of references.

The translation is just that, and not a transliteration as is so often the case — Betty Roquerbe and Maurice Burton are especially to be congratulated.

Illustrations are generally good, although some of the figures could have been improved by conforming in this edition to the usual American practice of having abscissa values increase from left to right, and by changing letter labels to English rather than French abbreviations.

After reading this delightful and scholarly book, the reader will find with real regret the author's obituary in an appendix. For Professor Bertin, who reveals himself in his work as a man of many parts; painstaking scientist, historian, linguist, wit, and gourmet, was killed in an automobile accident in 1956.

John P. Wise

Dick, William E. ATOMIC ENERGY IN AGRICULTURE. Philosophical Library. 1957. Pp. 146. $6.00

To the general scientific reader, this book presents excellent examples of how radioisotopes have been used in agriculture and agricultural research. The 1955 Geneva Conference inspired the author, and the six chapters of the book are six of the topics discussed at the Geneva Conference. These are: (1) Remaking crop plants with radiation; (2) Photosynthesis: Tracing the path of carbon with radioisotopes; (3) The path of the other elements; (4) Radioactive materials in the fight against pests; (5) Radioactive tracers and forestry; (6) Atomic radiation and food pre vation.

The author has neither attempte cover all the uses of isotopes in a culture nor succeeded in comprehens coverage of the subject matter in e chapter. Nevertheless the result i fascinating account of specific uses radioisotopes in agriculture.

The author is to be congratulated presenting enough background mate in each subject so that the uninfor can get a full grasp of both the sub matter and the role of atomic ene The lucid discussions should leave reader better informed on such subje as radiation genetics, the photosynth carbon cycle, plant nutrition, fertil usage, insect habits and control, r ation damage, the interrelationships tween trees in a forest, the movemen sap in trees, the problem of radioact wastes, types of radiation, and effe of radiation on microorganisms that ca food spoilage.

The lay reader will have diffic with many of these topics. However, previous knowledge of agricultural ence or atomic energy is necessary the general scientific reader to com hend and enjoy the various discussio

Maurice F

Celebonovic, Stevan, and Grig Geoffrey. THE LIVING ROC Philosophical Library. 1957. 94. Illus. $6.00. Preface by An Maurois. OLD STONE AGE. Ph sophical Library. 1957. Pp. Illus. $10.00.

These two books are the first i Nature and Art Series. With a large p size, 9¼ by 12½ inches, they give scope to the fine photographs by Celebonovic which are their chief feat The first volume gives a striking ass ment of close-up views of rock fo and fossils, with very brief explanatio A particularly irritating aspect of format is the placing of picture ti off by themselves at odd places in text, requiring much shuffling back forth to see what you have. This b would be of most use to people seek new design motifs, rather than to seri students of geology. The second bo on prehistoric art, has a more adeq text, but again the pictures are mor

The World's Southernmost Indigenous Cod

By

John P. Wise,

U. S. Fish and Wildlife Service, Woods Hole, Massachusetts

Introduction

The shoal waters to the south-east of Nantucket Island, bounded on the south by the 41st parallel of latitude, have long been tacitly considered the limit of the year-round distribution of the cod, *Gadus callarias* L., in the north-western Atlantic.

Dambeck (1879), Goode (1888), Tåning (1953), and Qasim (1956) have taken Cape Hatteras, N.C., at 35°10′N., as the extreme southern limit, although catches during the winter of 1926–27 were reported from Cape Lookout, N.C., 34°34′N., by Hildebrand (1941). Authorities agree that all southern location records are based on winter distribution. There is a report (Leslie, 1883) of "acres of codfish" seen floating belly up between Cape Hatteras and Cape Henry about 1. June, but the hearsay evidence presented is at best doubtful.

Recent catch statistics show that about five per cent. of the total United States catch of cod is taken in the Middle Atlantic and Chesapeake fisheries during the colder months of the year. Of the five per cent., the greater part, about 4·9%, is taken in the waters off the Middle Atlantic states of New York, New Jersey, and Delaware, and only negligible amounts in the Chesapeake states of Maryland and Virginia. During the summer months, according to fishermen's accounts, only rare stragglers are caught in any of these areas.

Bigelow and Schroeder (1953) hold that cod found to the south and west of Nantucket in winter are migrants from southern New England, and Schroeder (1930) considers a large part of them migrants from Nantucket Shoals which return to home grounds during the summer.

But certain unanswered questions have been raised by these same investigators concerning the rationale of the seasonal distribution of these cod. Schroeder was unable to find a plausible stimulus for what he interpreted as the annual winter migration to the south-west; he carefully considered water temperature, spawning, food supply, food competition, etc., but rejected each. He also dismissed the possibility of random spreading due to lack of temperature barriers in the winter, since no corroborating similar movements to the north or east can be demonstrated. Bigelow (1956) comments that "half" the fish on Nantucket Shoals move to the Long Island and New Jersey coasts in the autumn, although conditions at one end of the range are not demonstrably different from those at the other end.

Tagging Experiments

Pertinent tagging experiments to 1930

SMITH (1902) reported on 4,019 cod tagged and released in the vicinity of Woods Hole around the end of January during the years 1898–1901. These fish were captured near Nantucket in October and November, held as a source of eggs and milt for the Woods Hole hatchery, and released in the spent condition. Numbered pieces of sheet copper were secured with copper wire at various places on the fish. Returns averaged about 3·5%, coming from the Cape Cod–Nantucket area in the summer and from as far away as the New Jersey coast in the winter. No authenticated recoveries were reported north of Cape Cod.

SCHROEDER (1930) tagged nearly twenty-five thousand cod from the US Bureau of Fisheries vessels "Halcyon" and Albatross II" on Nantucket Shoals during the summers of 1923–29. Unfortunately, the mark used, a metal strap attached to the caudal peduncle, is easily lost by the fish and returns were low, about 3%. The recapture locations were generally similar to SMITH's with an occasional straggler returned from considerable distances to the north and east. In addition, he repeated SMITH's experiment, tagging 1859 fish at Woods Hole, with essentially similar results.

SCHROEDER also tagged an additional 746 cod during the winter of 1928–29 off the southern New Jersey coast. Fifteen recoveries were reported (SCHROEDER, 1930) and they are considered below.

Recent tagging experiment

We tagged 448 cod off southern New Jersey during the winter of 1955–56. The mark used is a Lea hydrostatic capsule (ROUNSEFELL and EVERHART, 1953) attached to a Monel chain which is in turn fastened to the centre of a plastic tab about $1\frac{3}{4}$ in. long by $\frac{1}{2}$ in. wide. The tags were fixed to the fish by making a small incision in the flank with a recurved scalpel blade and inserting the tab into the coelom, where it serves as an internal anchor for the Lea capsule. Tank tests at Woods Hole suggested no mortality on cod over 25 cm. in length. The incision heals rapidly around the chain and no toxic or deleterious effects have been observed on experimental or recaptured fish.

Fifty-three (nearly 12%) of the marked fish have been recaptured in the first seventeen months following tagging[1]).

Tag returns

Figure 1 shows return locations from SCHROEDER's New Jersey work and from the current tagging experiment plotted for the winter months, December-March, the transitional months, October-November and April-May, and the summer months, June-September. It is apparent that cod tagged off the New

[1]) Exact dates and locations of tagging and recapture are filed in the Council's offices in Copenhagen and may be obtained from there, or from the author, on request.

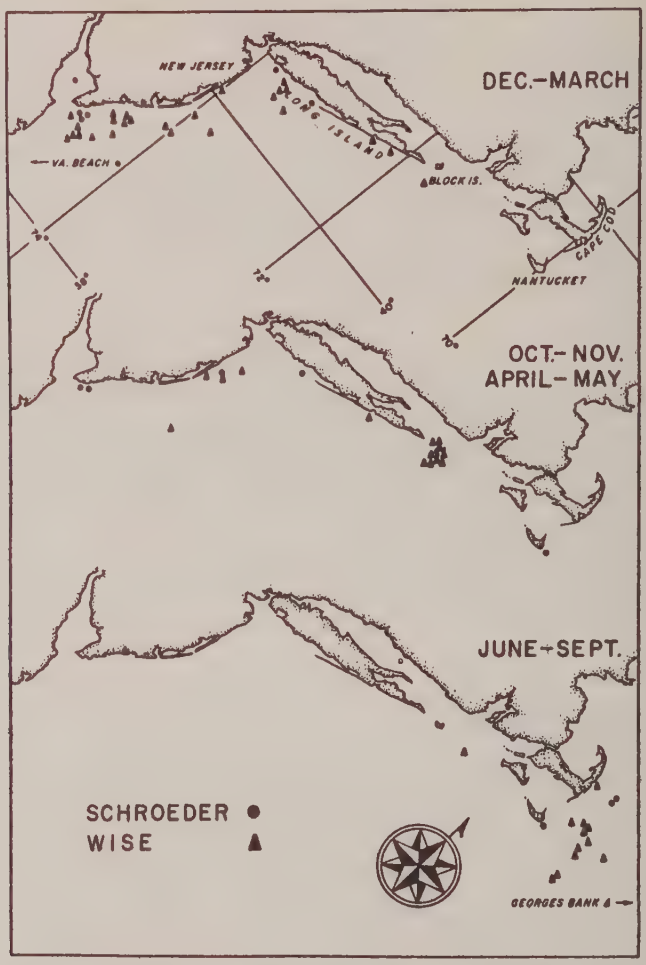

Figure 1. Locations of recaptures of cod from SCHROEDER (1930) and the current experiment. All fish were tagged off southern New Jersey in winter.

Jersey coast in winter are found north-east of Block Island only in the summer months (with a single exception in early October). During the winter they are concentrated on the New Jersey coast, and in the transitional periods they range from southern New Jersey to Block Island.

SMITH's results supported by SCHROEDER's repetition of the experiment show that some fish caught on Nantucket Shoals in October or November and released in January were found to the south-west during the winter, but we feel that cod after having been held for several months in live cars and stripped of eggs and milt cannot be expected to demonstrate reliable or completely normal patterns of behaviour immediately thereafter.

Conclusions

It may be seen, then, that it is possibly more appropriate and consistent with the facts gathered from tagging experiments to consider those fish found ranging from Nantucket Shoals to North Carolina as a separate group, at least partially independent from the southern New England cod with which they mingle in the warm months.

Discussion

This concept suggests an answer to at least one question previously raised. The autumn movement from Nantucket to the south-west is not a migration of part of the native fish in this direction, but rather a return of the Middle Atlantic cod to their native grounds after estivation in southern New England waters.

We saw ripe cod during the tagging work in 1956 off the New Jersey coast, and both SMITH and SCHROEDER mention the occurrence of these spawners. SCHROEDER also reports the finding of cod eggs and larvae by O. E. SETTE as far south as North Carolina. Therefore it is likely that this Middle Atlantic stock is not dependent on any other cod for recruitment, and that the return to native grounds in the winter is a spawning migration.

The proposed recognition of the Middle Atlantic cod as a discrete unit does not answer all the questions — rather it calls for a re-orientation, and examination of several important questions.

What stimulus initiates the movement to New England in late winter and early spring? What is the fate of the eggs and larvae which are carried further down the Atlantic coast by the general south-westerly drift (MILLER, 1952) prevalent in the spawning area? Further work on these and other problems may shed light on many aspects of a population which lives on the extreme fringe of the range of the species. Water temperature records may well furnish important clues here.

None the less, the seasonal movements fall generally into place, and this must be recognized as one of the wide ranging stocks of cod, comparable to the Lofoten cod of Norway. These North American cod also return annually to their home grounds to spawn.

An important difference, however, is that this appears to be the world's southernmost indigenous group of the species, spawning and spending most of its year between the 35th and 41st parallels of latitude, the latitudes of Portugal and North Africa in the eastern North Atlantic and of California in the Pacific.

Synopsis

The results of tagging experiments conducted by W. C. SCHROEDER in the winter of 1928–29 and the author in the winter of 1955–56 off the southern New Jersey coast of the United States have been analysed and show that cod thus tagged are found north-east of Block Island only in the summer months. During the winter these fish are concentrated on the New Jersey coast, and in the transitional periods they range from southern New Jersey to Block Island.

On the basis of this analysis it is proposed to recognize the cod which roam from Nantucket Shoals to North Carolina as a discrete group, indigenous to this area. This, then, is the southernmost unit of the species.

References

BIGELOW, H. B., and SCHROEDER, W. C., 1953. "Fishes of the Gulf of Maine". Fish. Bull. U S Fish and Wildlife Serv., **74**, 577 pp.

BIGELOW, H. B., 1956. "On fish and fisheries". Oceanus, **4** (2): 4–8.

DAMBECK, K., 1879. "Geographical distribution of the Gadidae or the cod family, in its relation to fisheries and commerce". Rep. US Fish. Comm., **5**: 531–57.

GOODE, G. B., 1888. "American fishes". 496 pp. Houghton, New York.

HILDEBRAND, S. F., 1941. "An annotated list of salt and brackish water fishes, with a new name for a menhaden, found in North Carolina since the publication of 'The fishes of North Carolina' by Hugh M. SMITH in 1907". Copeia 1941, **4**: 220–32.

LESLIE, C. C., 1883. "Scarcity of blackfish-mortality of codfish". Bull. US Fish Comm., **2**: 132.

MILLER, A. R., 1952. "A pattern of surface coastal circulation inferred from surface salinity-temperature data and drift bottle recoveries". Woods Hole Oceanographic Inst., unpublished MS, 52–28, 14 pp.

QASIM, S. Z., 1956. "Time and duration of the spawning season in some marine teleosts in relation to their distribution". J. du Cons., **21** (2): 144–55.

ROUNSEFELL, G. A., and EVERHART, W. H., 1953. "Fishery science, its methods and applications". 444 pp. Wiley, New York.

SCHROEDER, W. C., 1930. "Migrations and other phases in the life history of the cod off southern New England". (Fish. Doc. 1081) Bull. US Bur. Fish., **46**: 1–136.

SMITH, H. M., 1902. "Notes on the tagging of four thousand adult cod at Woods Hole, Massachusetts". Rep. US Fish Comm., **27**: 193–208.

TÅNING, Å. V., 1953. "Long-term changes in hydrography and fluctuations in fish stocks". ICNAF, Ann. Proc., **3** (5): 69–77.

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AN ALL-PLASTIC DART-TYPE FISH TAG[1]

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Honolulu, T. H.

INTRODUCTION

The Pacific Oceanic Fishery Investigations (POFI), of the U. S. Fish and Wildlife Service, has been studying the skipjack (*Katsuwonus pelamis*) in Hawaiian waters as part of its program to assist the fisheries of the Pacific area. Two aspects of the biology of the skipjack on which there is presently little information are its migrations and growth. Tagging offers a direct means of obtaining information on these problems.

Employing the principle of the harpoon and utilizing plastic materials, a new fish tag has been developed which appears quite promising. The present model, patterned to some extent after the Woods Hole dart tag (through personal correspondence), has been designated the POFI D-2 tag.

Recoveries have been markedly higher than those from tags used in earlier large scale tuna tagging programs. For instance Godsil (1938) tagged 4,000 yellowfin tuna (*Neothunnus macropterus*) and skipjack with opercular disk tags and obtained no recoveries. The first successful tuna tag was developed by the California Department of Fish and Game (Wilson, 1953). This tag, in the form of a loop of plastic tied through the flesh immediately posterior to the base of the second dorsal fin, gave worthwhile returns on yellowfin tuna and albacore, but returns were low on skipjack. Our own experience is illustrative. Between 1954 and 1956, 1,961 skipjack, tagged in Hawaiian waters with the California tag, yielded 12 returns, including three from the stomachs of predators. This rate of predation may be attributed to the length of time required to attach the type G tag. As a result of its struggles during this period the skipjack is in a weakened condition when returned to the water. In this weakened condition skipjack tagged with the type G tag are more susceptible to predation than are skipjack tagged by a more rapid method. In contrast, 747 of 8,161 skipjack, that were tagged with dart tags in 1957, have been recovered, none in the stomachs of predators. Recoveries are still being made, and to date, the longest time at liberty has been 260 days. Recoveries from individual groups of 3,224 and 2,291 skipjack, tagged and released in 1957, equal 11 and 13 percent respectively.

The probable reasons for the success of the new tag are: (1) its application involves minimum handling of the fish; (2) it remains firmly anchored in the fish; (3) it is small and offers little resistance to the

[1] Submitted for publication May, 1958.

flow of water; and (4) it does not interfere with the fish's normal activity. An additional advantage is that the speed of application permits operators to release a maximum number of tags during the course of tuna live-bait fishing.

With respect to other fishes, the Wisconsin Conservation Department (personal communication) has conducted pond tests on lake sturgeon (*Acipenser fulvescens*) and found the tag better than other types used. They also obtained preliminary results suggesting the tag could be used on walleye (*Stizostedion vitreum*) and lake trout (*Cristivomer namaycush*).

CONSTRUCTION

Tag

The POFI D-2 tag (Figure 1) has two parts, a head with a barb and a streamer. The head is a Lucite rod, thirteen-sixteenths of an inch in length, and the streamer is a plastic tube five inches in length. The

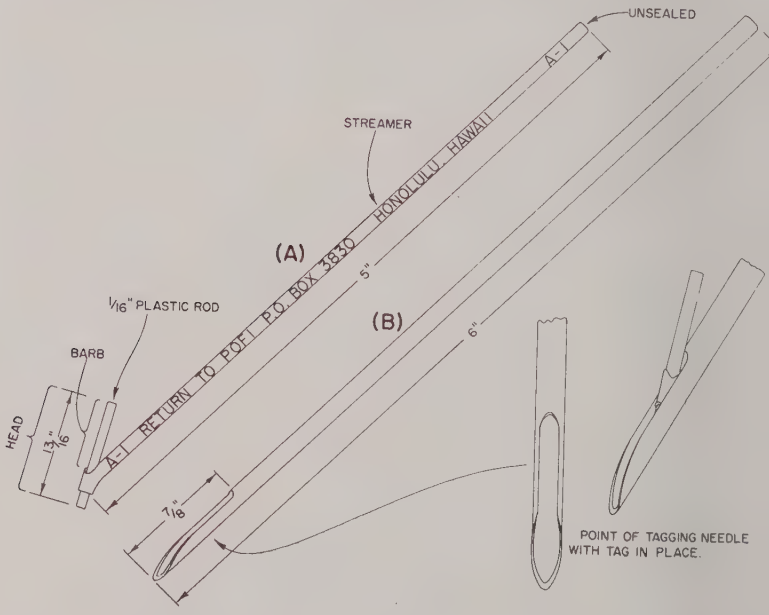

FIGURE 1. Diagrams of: (A) POFI D-2 tag and (B) tagging needle.

head is passed through a 45-degree cut made one-eighth inch from one end of the streamer, and these two parts are fastened together with a waterproof glue. A legend and serial number are printed on or contained within the streamer. The component parts and labor involved in fabrication of 1,000 tags is estimated at $95, while the cost of producing 100 needles approximates $57, but these latter are reusable and losses are minimal (Table 1).

TABLE 1
Components and Cost of POFI D-2 Tag and Needle

Part	Description	Manufacturer or other source	Cost
Tag			
Head	Lucite rod (1/16 in. dia.)	Local plastics supplier	$5.40/1,000 tags
Streamer	Resinite EP-2 AWG size 13	The Borden Company Chemical Division P.O. Box 1589 Santa Barbara, Cal.	$5.85/1,000 tags
Waterproof glue	Seal-All	Allen Products Corp. 20450 Sherwood Ave. Detroit 34, Mich. (obtained from local hardware supply)	$0.34/¾-oz. tube
Legend	Machine printed, using vinyl plastic ink	Printing by: Hugh C. McCoy 16400 Third Ave., SW. Seattle, Wash.	$25.00 + $0.225 (ink)/1,000 tags
Ink	Black vinyl plastic (No. 104N5A4)	California Ink Co. 546 Sansome St. San Francisco, Cal.	$1.35/4-oz. bottle
Labor	Serial number and assembly	Mr. James Suyenaga 1172 Puu Poni St. Pearl City, T. H.	$55.00/1,000 tags
Total cost/1,000 tags			$95
Needle			
Stock	No. 3 tempered stainless steel 5/32 in. OD × .016 in. wall	Tubesales, Inc. 2211 Tubeway Los Angeles 22, Cal.	$54.00/100 ft. (= 200 needles)
Labor	Cutting groove and sharpening point	Precision Industries 754 S. Queen St. Honolulu, T. H.	$30.00/100 needles
Total cost/100 needles			$57

Tag Modifications

The head on the present tag is blunt at both ends, whereas the earlier models had a sharpened barb to aid in firmly anchoring the tag. Sharpening the barb was found to be unnecessary.

The original streamer consisted of a clear plastic jacket, to which the head was attached, and a red or blue tubular plastic insert which bore the legend. A red, printed paper slip was later substituted for the plastic insert, and this gave a more readable legend. To protect the paper or plastic insert, the end of the outer jacket was plugged with a short piece of Lucite rod dipped in glue. The most recent modification of the streamer involves printing the legend and serial number, one at the base and another at the end of the streamer, directly on a red opaque tube, thus eliminating the insert and the plug. The red is preferred to the blue because the legend is more legible and the color is more obvious to the human eye.

Recovered tags have shown some fading of color and legend on the streamers and streamer inserts. This appears to have been caused by sunlight, because on many of the tags only the upper side of the protruding portion of the streamer is faded. The under side and the portion of the streamer inside the fish retained the color and legend. Efforts are being made to find an ink and a plastic that are less affected by sunlight.

Tagging Needle

The tag is inserted with a stainless steel needle (Figure 1B) similar to that used for California type G tags. The point is cut as shown in the figure, so the tag head will be held securely. Without this feature the tip slips out of the groove, the head turns across the axis of the needle, and the streamer is cut off when the needle is inserted into the fish. The needle should be of sufficient length so that the end of the streamer does not protrude.

TAGGING PROCEDURE

Before fishing begins, a number of needles are loaded with tags and bound in bundles of 10. On most POFI trips, 400-500 needles are so prepared. Each bundle is labeled with a slip of waterproof paper bearing the serial numbers of the tags. Since individual measurements of fish are not taken it is not necessary to identify individual tag numbers at the time of tagging. Instead the labels and the unused tags from a bundle of 10 are retained and checked after each fishing period or day to determine what numbers were released. A tagger can carry as many as 100 tags in the pockets of a canvas apron.

The D-2 tags have been employed principally in tagging skipjack caught by pole-and-line fishing. Tags of five-inch length have been used satisfactorily on fish ranging from 2 to 25 pounds. In the fishing operation, as commonly practiced by Hawaiian fishermen, skipjack are hooked, swung up, caught under the left arm, and unhooked. The tagger stands one to two feet behind the fishermen; ordinarily there is one tagger to two fishermen. After the skipjack is caught and while the hook is being removed, the tag-bearing needle is inserted usually from the right side, about one-half to one inch below the crest of the back and between the end of the second dorsal fin and the insertion of the first dorsal finlet. When the needle is removed, the barb holds the tag in place. The needle should form an angle of about 45 degrees with the body surface of the fish, and should be inserted with the barb next to the fish and deep enough so that the head of the tag crosses the median sagittal plane. The barb will then lodge against a neural spine and firmly anchor the tag in the fish. If the tag is inserted with the barb next to (Figure 2A), rather than away from (Figure 2B) the side of the fish, the tag will also be firmly anchored, even though the head does not cross the sagittal plane. The exact placement does not seem important as long as a major blood vessel is not injured. It is important that the end of the streamer does not reach the caudal fin, or the fin will be frayed by swimming movements of the fish. Small fish should be tagged anterior to the second dorsal fin in order to prevent this injury of the caudal fin.

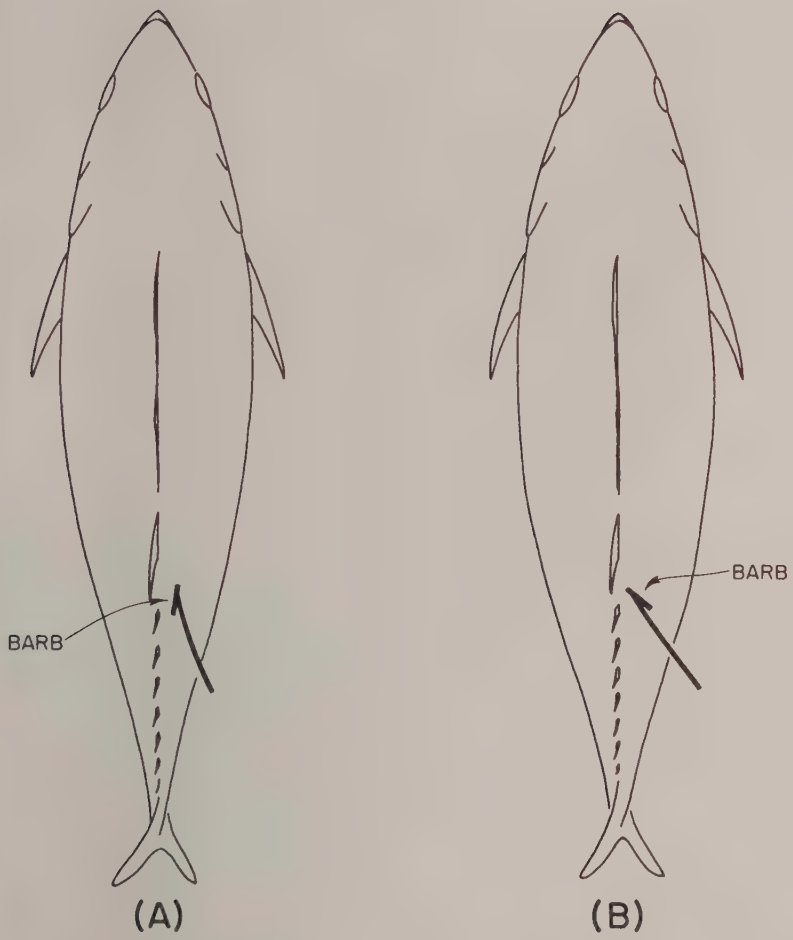

FIGURE 2. Diagrams showing dorsal view of tagged fish with barb inserted (A) next to and (B) away from side of fish.

Individual skipjack may be hooked, tagged, and returned to the water in as little as four seconds. Measurements of skipjack cannot be taken in this short time; instead, the size of tagged fish may be estimated from measurements of untagged fish caught from the same school. This estimate is considered to be reliable, because it has been shown that skipjack school by size (Brock, 1954).

EFFECT OF TAGGING ON FISH

Underwater observations of tagged skipjack indicate that they are not greatly affected by the tagging procedure nor by the presence of the tag. Tagged fish were observed to sound, then return to the portion

of the school around the vessel. There have been seven instances in which tagged skipjack were recovered within minutes of being released. During the fall of 1957 one skipjack was tagged twice and released twice. The fish was initially tagged and released on November 20th. Three days later it was recovered by POFI fishermen and a second tag was inadvertently placed on it before it was again released. Fourteen days later this twice tagged skipjack was recovered by a commercial fisherman.

The tagging wound heals rapidly with no infection. Scar tissue is present within 10 days of tagging and well developed within a month. The scar tissue does not usually fuse to the tag but forms a tight, glove-like pocket around the head and streamer. The external wound is small, scarcely larger than the streamer (Figure 3).

SUMMARY

An all plastic, dart-type fish tag was used with considerable success on skipjack in Hawaiian waters during 1957. Recoveries from individual groups of 3,224 and 2,291 fish equalled 11 and 13 percent respectively. In addition to the high percentage of recovery the tag has

FIGURE 3. Skipjack with D-2 tag recovered 30 days after release. Tag pulled forward to show small wound and growth of new skin around opening. *Photograph by K. D. Waldron, June, 1957.*

other desirable characteristics such as: (1) small size; (2) simplicity and rapidity of application; (3) low resistance to water flow; (4) secureness when attached properly; (5) negligible effect on the natural movements of the fish; and (6) one uniform size may be used on fish weighing between 2 and 25 pounds. Because of these advantages the dart tag should be suitable for use on a great variety of fishes.

REFERENCES

Brock, Vernon E.
1954. Some aspects of the biology of the aku, *Katsuwonus pelamis*, in the Hawaiian Islands. Pacific Science, vol. 8, no. 1, pp. 94-104.

Godsil, Harry C.
1938. Tuna tagging. Calif. Fish and Game, vol. 24, no. 3, pp. 245-250.

Wilson, Robert C.
1953. Tuna marking, a progress report. Calif. Fish and Game, vol. 39, no. 4, pp. 429-442.

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Improved *N*-Ethylcarbazole Determination of Carbohydrates with Emphasis on Sea Water Samples

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▶ A modified method for determination of carbohydrates in sea water with *N*-ethylcarbazole will determine as little as 1 γ of carbohydrate per ml. of sample. There is no salt interference and, with the exception of xylose and fructose, pentoses, hexoses, and their polymers yield the same amount of color per unit weight.

THE USE of *N*-ethylcarbazole as a reagent for the determination of carbohydrates in sea water was developed originally by Erdman (*7*). It was used extensively by Collier *et al.* in various experimental studies (*1–3*), and as a routine method for the measurement of the carbohydrate content of sea water in this laboratory from 1951 to 1956. The technique is ad-

vantageous in sea water studies because it measures total carbohydrate content rather than that of specific classes of carbohydrates. This method often gives a very low slope and is extremely sensitive to changes in temperature, to light, and to various types of contaminants. In an effort to improve this method for routine sea water analysis, the technique has been reexamined with regard to heating time, method of reagent addition, reagent concentration, and precision. The reaction of this reagent with various sugars has been studied under these revised standardized conditions.

METHOD

Purification of *N*-Ethylcarbazole. *N*-Ethylcarbazole obtained in crude form from the Reilly Tar & Chemical Corp. is dissolved in hot alcohol and allowed to crystallize. The mother liquor from this crystallization is discarded because it contains most of the impurities. The crystals are then redissolved in hot alcohol and allowed to recrystallize, and the mother liquor is treated with an equal volume of distilled water to precipitate the remaining *N*-ethylcarbazole. This process of recrystallization from warm alcohol followed by water precipitation is continued until pure white needle-shaped crystals are obtained. The adsorbed alcohol is removed by drying the crystals at a temperature no higher than 55° C. (*N*-ethylcarbazole decomposes at 69° C.). The dried purified compound dissolved in acid and treated as a routine blank sample as described below, should give a scale reading less than 4.5 in the 23-ml. cuvette of a Fisher Electrophotometer; this is equivalent to an absorbance reading on the Beckman DU spectrophotometer in a 1-cm. cuvette at 560 mμ, of no more than 0.020. Starting with approximately 1 pound of crude *N*-ethylcarbazole dissolved in 2 liters of hot alcohol yields pure compound sufficient for 8000 determinations. Best results are obtained if the alcohol is heated first and the crude compound or crystals added so slowly that they dissolve readily. Heat that is too strong or too direct causes the *N*-ethylcarbazole to melt and decompose, rather than to dissolve.

Acid. Du Pont C.P. sulfuric acid, full strength.

Reagent. One gram of purified *N*-ethylcarbazole per liter of concentrated sulfuric acid. Usually 2.2 liters are prepared directly in the acid bottle, mixed well, and divided into equal parts in two amber glass bottles fitted with amber glass automatic acid burets. This reagent may be stored in the cold, but the storage period should not exceed 48 hours because the standard slope decreases both with age and chilling. Results are more satisfactory if the reagent is used immediately after preparation. If amber glass equipment is not used, additional precautions must be taken against light—e.g., the reagent must never be left in open sunlight or exposed to light containing considerable ultraviolet. All glassware used in the preparation and transfer of the reagent should be rinsed with Du Pont C.P. sulfuric acid before use.

Procedure. Samples of 3 ml. each are pipetted in duplicate into 50-ml. Erlenmeyer flasks and covered with 30-ml. beakers. To groups of 12 samples (six duplicates), reagent is added as follows. (Times indicated are counted from the initial addition of reagent to the first sample.) At time 0, 5 ml. of reagent are added to sample I from buret I. After 30 seconds, 5 ml. of reagent are added to sample II from buret II. At 60 seconds, 22 ml. more of reagent are added to sample I from buret I, and at 90 seconds, 22 ml. more of reagent are added to sample II from buret II: the burets are refilled with reagent and a second pair of samples treated in the same way. This procedure is followed until reagent has been added to all 12 samples. The samples are then placed in a water bath at 70° C. for 30 minutes, after which they are brought to room temperature in a refrigerator. They are then read against distilled water, either in a Fisher Electrophotometer fitted with a G.A.B. 560 mμ interference filter (Photovolt Corp., New York, N. Y.), or the 525 mμ B filter. Samples may also be read in a Beckman DU spectrophotometer at 560 mμ, but this is not recommended for the routine handling of large numbers of samples. When this instrument is used, a 5-cm. cell should be used for concentrations below 4 or 5 mg. of carbohydrate per liter. In the experiments described, readings with the Electrophotometer have been made using a single 23-ml. cuvette nulled with distilled water. Spectrophotometer readings have been made using four 1.00-cm. Corex cells balanced within 2% at 544 and 560 mμ; a single cell has been used for a null and the remaining three have been used as sample cells. The spectrophotometer slit width was held at 0.04 mm.

Blanks and a set of standards in triple distilled water must be run with each batch of reagent prepared. D(−)-arabinose was used in concentrations of 1.0, 2.0, 3.0, 5.0, and 10.0 mg. per liter (0.67×10^{-5}, 1.33×10^{-5}, 2.00×10^{-5}, 3.33×10^{-5}, and 6.67×10^{-5} mole per liter). These standards are run in duplicate, the best straight line is calculated through the points, and the sample concentrations are obtained from the slope of this line.

Precautions. All glassware must be scrupulously clean. Flasks and beakers used in this determination are soaked overnight in Du Pont C.P. sulfuric acid, rinsed repeatedly in triple distilled water, and allowed to drain dry. The amber bottles and burets from which the reagent is dispensed are rinsed with triple distilled water after each use, and with fresh acid before the next use.

In the presence of high concentrations of nitrate the reagent will turn green, masking the pink color formed by the reaction of the carbohydrates and the reagents. A few samples have been found to turn orange when reagent was added but this contaminant is as yet unidentified.

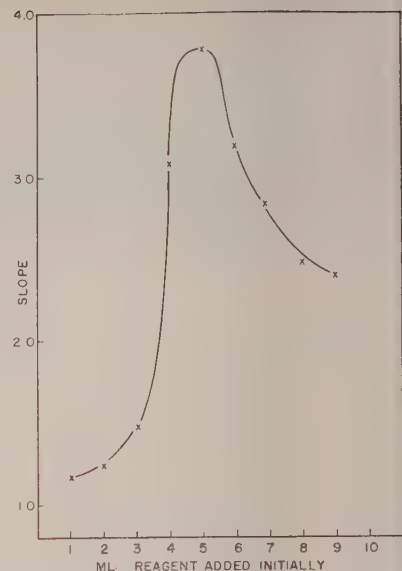


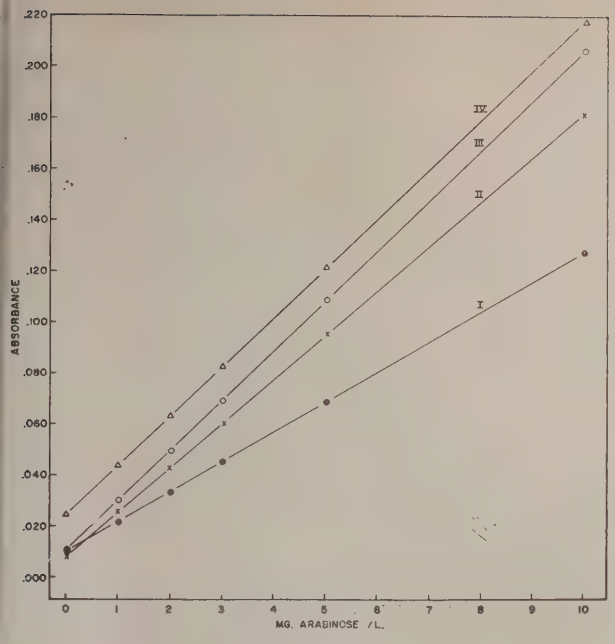
Figure 1. Slope *vs.* milliliters of *N*-ethylcarbazole added initially

Bubbling of the samples after pouring into the cuvette is reduced by the use of flasks with 30-ml. beakers as caps; loose fit of the beakers allows many hydrochloric acid bubbles to escape during the heating period. Careful attention must also be paid to the cooling period. Samples must be at room temperature and not below, to prevent condensation, but samples that are still warm will read less than those at room temperature. Samples should be poured carefully to prevent the formation of hydrochloric acid from salt sometimes deposited around the neck of the flask.

RESULTS

Effect of Two-Stage Addition of Reagent. The intensity of color produced was greater when the reagent was added as a two-stage delivery rather than as a single stage as suggested by Erdman. To find the optimum initial addition of reagent, ten sets of standards were prepared as described above and the Erdman procedure, which adds 9 parts of reagent to 1 part of sample (27 ml. to 3 ml.), was modified.

One milliliter of reagent was added to each of the first set of samples. The amount of reagent was then increased by a 1-ml. increment per set, so that each sample of the last series received 10 ml. as a first-stage addition. Each sample was allowed to stand for 1 minute and the remainder of the 27 ml. added (26 ml. for the first set, etc.). Samples were heated and cooled as usual, and read in the electrophotometer. The slope for each set of standards was plotted against the amount of reagent added initially (Figure 1).



◀ Figure 2. Variation of slope with *N*-ethylcarbazole concentration

Grams *N*-ethylcarbazole per liter

I. 0.5
II. 1.0
III. 2.0
IV. 3.0

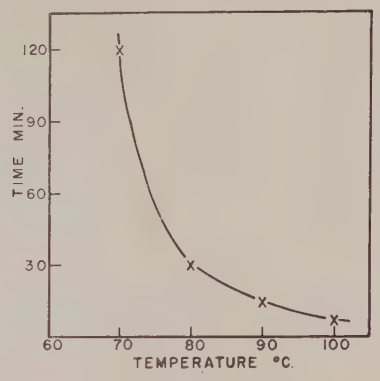


Figure 3. Influence of temperature on time of formation of green reagent-acid compound

The initial addition of 5 ml. of reagent gave the highest slope. With less reagent, the *N*-ethylcarbazole tended to precipitate in the water phase; this reaction may be a contributing cause of the lower slope. An error in delivery of ±0.5 ml. of reagent is not significant. Although some *N*-ethylcarbazole may precipitate on the low side of 5.0 ml. and the color initially developed may be noticeably decreased, total color develops normally with heating. This may indicate that the increased color in the two-stage procedure results from the accelerated formation of colored reaction products by the heat arising from dilution of the sulfuric acid. Longer standing periods between reagent additions were also tested but the increase in slope when standing time was changed from 1 to 2 minutes was not large enough to justify the use of the longer period on a routine basis.

Effect of *N*-Ethylcarbazole Concentration. Although Erdman suggested the use of 1.0 gram of *N*-ethylcarbazole per liter of sulfuric acid, several concentrations of reagent were checked to determine whether the slope obtained with the two-stage method could be further improved. Four batches of reagent were prepared using the same lot of purified *N*-ethylcarbazole and acid from a single bottle. The *N*-ethylcarbazole concentration ranged from 0.5 to 3.0 grams per liter of acid. A set of standards was run by the method described using each reagent concentration, and the samples were read on the spectrophotometer at 544 and 560 mμ. The slope was plotted for each concentration of reagent as shown in Figure 2. Doubling the concentration between 0.5 and 1.0 gram per liter increased the slope by 50%, while doubling between 1.0 and 2.0 grams per liter raised the slope only 15%, and the further increase to 3.0 grams per liter caused no significant increase above that of 2.0 grams per liter. For practical reasons (expense of crude reagent and the time involved in purification), increasing the concentration above 1.0 gram per liter seemed undesirable. Therefore all further experiments were performed using 1.0 gram of *N*-ethylcarbazole per liter of acid.

Effect of Temperature and Heating Time. In Erdman's original technique, samples were heated at 70° C. It was thought that raising the temperature might enable the heating time to be reduced. However, the length of time samples remained in the water bath was far more critical at higher temperatures. There was an apparent tendency for the *N*-ethylcarbazole to react with the acid to form a green compound which gradually darkened and appeared black. This side reaction was accelerated by increased heat, and apparently varied both with the particular bottle of acid and the lot of purified *N*-ethylcarbazole. The magnitude of the masking effect of the reagent-acid compound upon the carbohydrate-reagent compound is dependent to some extent upon the individual sugar. High carbohydrate concentrations (5 to 10 mg. of carbohydrate per liter) also are less affected than lower concentrations. This suggests a competition between the acid and the carbohydrate for the reagent molecules.

Figure 3 shows the influence of temperature on the time of formation of the green reagent-acid compound. The color change may be reversed by shaking and cooling the samples within 1 or 2 minutes following development of the green color, but after this time the change becomes irreversible. Because of this increased instability of the reagent at higher temperatures, further time checks were made at 70° C.

Using a single batch of reagent, sets of standards were run as usual varying the heating time from 10 to 30 minutes. Samples were cooled and read in the spectrophotometer. Figure 4 shows the relationship of time of heating and slope for such an experiment. There is a significant increase in slope between 10 and 15 minutes, and between 15 and 20 minutes of heating. However, the increase between 20 and 30 minutes is slight. Further testing of these two heating times indicated that the increase in slope between 20 and 30 minutes was statistically significant, with a t value for the comparison of slopes significant at the 2% confidence level. The 30-minute time interval was selected for routine use.

Dische, in his work with carbazole (4) emphasized that all samples should be chilled before and during the addition of reagent to increase the precision, and to control the heat generated by dilution of the reagent. This cooling procedure, as suggested by Dische, was tried with the Erdman method.

The reagent was prepared as usual and precooled in the refrigerator. One set of standards was pipetted and left at room temperature and the entire 27 ml. of reagent were added to the warm samples without any standing period. Cooled reagent was added to the flasks prepared for the second set of standards, the samples were pipetted carefully into the flasks which were in an ice

Figure 4. Variation of slope with time of heating at 70° C.

Heating time, min.
I. 10
II. 15
III. 20
IV. 30

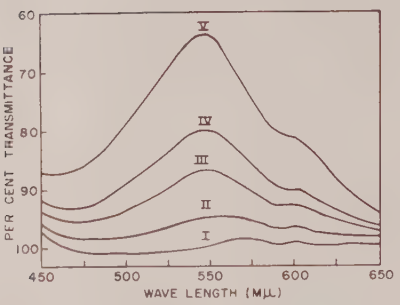
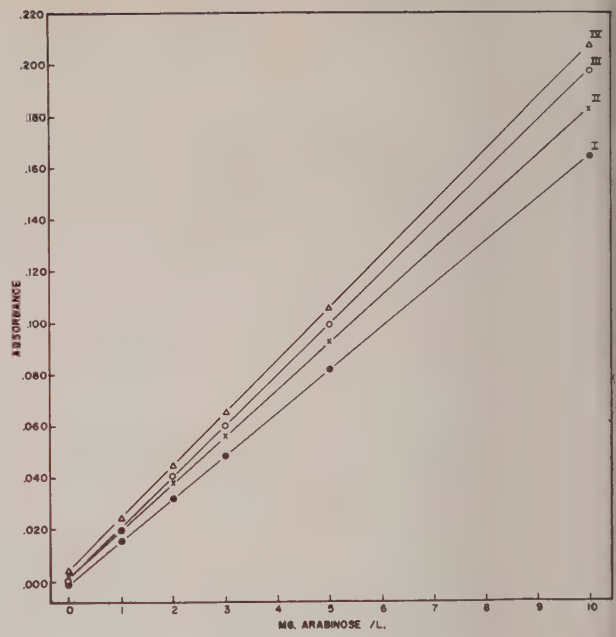


Figure 5. Absorption spectra of arabinose–*N*-ethylcarbazole compounds

Mg. arabinose per liter
I. Blank
II. 1
III. 3
IV. 5
V. 10



bath, and the flasks were swirled to mix reagent with sample. Both sets of standards were then placed in the hot water bath and heated. The complete range of temperatures, 70° to 100° C. was tested as described.

At no temperature did the chilled samples produce as much color as the samples treated at room temperature when both were heated the same length of time. Most chilled samples showed only half the color of the samples at room temperature as indicated by absorbance readings. Precision with the two methods appeared to be the same and the advantage of using room temperature was such that there was no further testing of this procedure using the modified method.

A better slope results when the reagent is freshly prepared in acid kept at room temperature than when it is made in quantity, stored in the refrigerator, and used cold.

Effect of Salt Concentration. Because several of the well-known carbohydrate methods show a definite salt effect—e.g., anthrone—the method was tested on standards made up both in distilled water and in Brujewicz artificial sea water. No statistically significant difference was found either in slope or in precision between the two sets of standards, although the usual precautions to prevent bubbling are necessary when the salt water standards are used.

Effect of Brand of Acid. The brand of acid used was most important. Of five brands tested, Du Pont C.P. sulfuric acid gave the most satisfactory blanks. Three of the five acids were unusable. One gave a deep pink color upon the addition of the *N*-ethylcarbazole to the acid while the other two became green. The Du Pont acid, as well as the fifth brand, showed only a pale straw color after *N*-ethylcarbazole was added.

Stability of Color of Carbohydrate-Reagent Compound. The stability of the colored compound to light was also checked. Standards of 1, 5, and 10 mg. of arabinose per liter were prepared and run in duplicate by the usual method, except that samples were brought to room temperature by slow cooling in a dark cabinet. When room temperature was reached, one set of duplicates was placed under a fluorescent lamp, while the other set was left in the cabinet. Readings were made with the spectrophotometer at 544 mμ at 10-minute intervals to determine changes in absorbance with time. Representative data are given in Table I. Thus samples kept in the dark will maintain constant color for at least 4 hours, while illuminated samples show increasing color, the proportion of increase being much greater for these samples of lower concentration.

Precision within Batches of Reagent. A batch of reagent was made up as usual and divided between two bottles. Six sets of standards were set up using the same volumetric pipet for each sample. The 12 blanks to be used in all six sets were pipetted successively, followed by the 12 1-mg. standards. This was repeated for each group, ending with the highest concentration, which was 10 mg. of arabinose per liter. The usual procedure was followed, using sets of standards consisting of the usual concentrations (blanks, 1, 2, 3, 5, and 10 mg. of arabinose per liter) in duplicate. The samples were read simultaneously, one operator reading the Beckman DU spectrophotometer at 544 and 560 mμ, and a second operator reading the Fisher Electrophotometer using the special filter described. Three cells were used in reading the spectrophotometer, while a single cell was used with all Electrophotometer readings. Statistics for this experiment are given in Tables II and III.

Standard deviations between duplicates were 0.21 mg. per liter of arabinose for Beckman readings at 544 mμ, 0.24 mg. per liter for Beckman readings at 560 mμ, and 0.16 mg. per liter for Fisher readings. These figures compare well

Table I. Absorbance Changes with Time

Time, Min. after Reaching Room Temperature	Absorbance					
	Dark			Illuminated		
	1[a]	5	10	1	5	10
0	0.037	0.097	0.190	0.034	0.103	0.186
30	0.037	0.097	0.190	0.041	0.108	0.187
60	0.037	0.098	0.191	0.044	0.117	0.190
100	0.037	0.098	0.191	0.042	0.118	0.188
180	0.037	0.098	0.192			
240	0.037	0.098	0.192			

[a] Concn. of arabinose in mg. per liter.

with values determined during routine analyses involving thousands of samples. They are, however, almost three times the values reported by Lewis and Rakestraw (*8*) using sucrose as a standard. For this reason results were routinely carried only to tenths of a milligram, in contrast to the values of Lewis and Rakestraw, which are reported to hundredths of a milligram.

A *t* test, comparing the values determined with the Fisher with those of the Beckman at 544 mμ, showed that the differences were not significant at the 5% confidence level. Differences are just significant at the 5% level when the concentrations calculated from the Fisher data are compared with those calculated from the Beckman data at 560 mμ. This may be partly due to the fact that the Beckman readings at 560 mμ are taken at a point where the slope of the absorbance curve is changing rapidly. Moreover the interference filter does pass light of wave length 544 mμ, so that Fisher readings are a result of absorption over this entire region. This, and the inability of the operator to distinguish small differences in readings, are undoubtedly factors which account for the greater precision between duplicate readings when the Fisher Electrophotometer is used.

Furthermore, the light path of the Fisher 23-ml. cuvette is over twice that of the Beckman 1-cm. Corex cell. A slightly greater precision might also be expected because of the use of a single cell with this instrument. Experiments using a single cell with the Beckman have emphasized the necessity for rinsing the cells with the solution to be read; samples of higher concentrations (5 and 10 mg. of arabinose per liter) are particularly susceptible to dilution effects with readings varying as much as 10% in absorbance when the standard of the next higher concentration is read without rinsing out the previously read lower concentration.

Studies of Reaction Product Formed between Carbohydrates and *N*-Ethylcarbazole Reagent. Solutions of various carbohydrates of the best commercial grades available were prepared at concentrations equivalent to 1, 2, 3, 5, and 10 mg. of arabinose per liter (see molarities given above) in distilled water. Each compound was run in duplicate by the routine method, cooled, and read in the spectrophotometer against distilled water after a trace of the compound spectrum had been made with the Cary recording spectrophotometer, Model 10 M.

Two types of absorbance spectra were observed, the type depending upon the classification of the sugar. The pentoses, arabinose, xylose, ribose, and lyxose showed a peak of maximum absorption at 544 mμ, with a secondary peak at about 600 mμ. The hexoses, glucose, fructose, galactose, mannose, and sorbose as well as their di- and oligosaccharides, maltose, lactose, sucrose, turanose, trehalose, melibiose, melezitose, and α-methyl glucoside showed a single maximum at 560 mμ, while the methylated sugars (fucose and rhamnose) as well as ascorbic acid showed a single maximum at 548 to 550 mμ. Figures 5, 6, and 7 give representative Cary traces of the pentoses and hexoses as well as the family of curves of the arabinose standard.

To minimize errors in the calculation of absorptivity arising from the observations, individual values were determined for each concentration of each sugar using the formula

$$a = A/bc$$

Table II. Precision within Bottle of Reagent

(Fisher Electrophotometer)

Sample[a]	Concn. of Arabinose, Mg./L. 0 $A \times 10^2$	1 $A \times 10^2$	2 $A \times 10^2$	3 $A \times 10^2$	5 $A \times 10^2$	10 $A \times 10^2$
I	5.3	9.2	12.4	16.2	23.3	41.3
	4.8	8.6	12.0	16.0	23.9	40.6
II	5.4	8.6	12.0	16.1	24.3	39.3
	5.6	8.6	12.0	15.6	23.6	39.4
III	5.0	8.5	12.0	16.0	23.0	40.9
	5.5	8.0	11.5	15.7	23.3	40.5
IV	4.2	7.9	11.5	15.5	23.5	41.0
	4.8	8.0	11.2	14.8	22.6	40.0
V	5.1	8.8	13.5	15.5	23.0	40.0
	4.2	7.3	11.9	14.6	22.5	40.0
VI	5.4	8.0	11.8	15.4	22.5	41.4
	4.7	8.0	11.8	15.5	22.0	39.1
Std. dev.	0.475	0.513	0.574	0.490	0.658	0.781
Regression coefficient[b]	3.551					
S_b	0.0218					
Deviation from regression	0.6120					
Variance between duplicates	0.2642					
Variance between samples	0.9516					
$F = 3.65$[c]						

[a] Samples refer to set of standards heated, cooled, and read as one group.
[b] Computed using all observations individually.
[c] $F = \frac{\text{between samples}}{\text{duplicates}}$; significant above 1% confidence level.

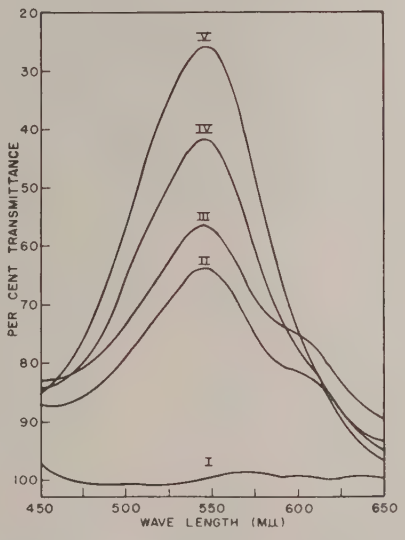


Figure 6. Absorption spectra of pentose-*N*-ethylcarbazole compounds

I. Blank
II. 10 mg. arabinose per liter
III. 10 mg. lyxose per liter
IV. 10 mg. xylose per liter
V. 9.8 furfural per liter

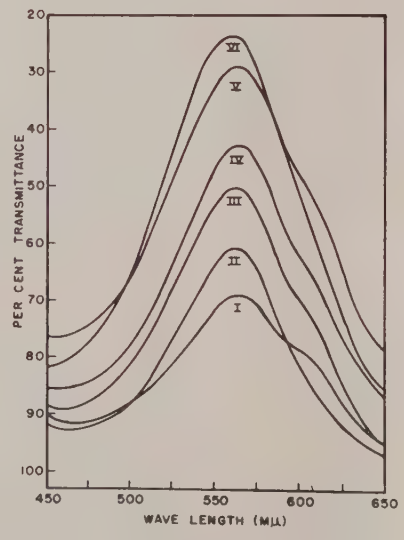


Figure 7. Absorption spectra of hexose-*N*-ethylcarbazole compounds

I. 10 mg. galactose per liter
II. 10 mg. glucose per liter
III. 10 mg. fructose per liter
IV. 24.4 mg. melibiose per liter
V. 28.8 mg. sucrose per liter
VI. 29.1 mg. melezitose per liter

Table III. Precision within Bottle of Reagent

(Beckman Spectrophotometer)

	Concn. of Arabinose, Mg./L.											
	0		1		2		3		5		10	
Sample[a]	A_{544}[b]	A_{560}	A_{544}	A_{560}	A_{544}	A_{560}	A_{544}	A_{560}	A_{544}	A_{560}	A_{544}	A_{560}
I	0.006	0.010	0.030	0.029	0.045	0.044	0.076	0.070	0.108	0.095	0.213	0.180
	0.013	0.016	0.034	0.034	0.049	0.046	0.067	0.060	0.118	0.103	0.208	0.177
II	0.016	0.020	0.032	0.032	0.050	0.050	0.076	0.069	0.113	0.099	0.205	0.170
	0.015	0.020	0.035	0.035	0.050	0.048	0.070	0.062	0.115	0.100	0.204	0.173
III	0.018	0.021	0.037	0.037	0.052	0.050	0.080	0.075	0.116	0.103	0.210	0.181
	0.016	0.020	0.035	0.034	0.050	0.047	0.071	0.065	0.110	0.100	0.211	0.184
IV	0.009	0.011	0.032	0.033	0.051	0.049	0.070	0.064	0.112	0.099	0.216	0.187
	0.016	0.020	0.035	0.035	0.048	0.045	0.075	0.066	0.115	0.101	0.206	0.176
V	0.009	0.011	0.035	0.034	0.061	0.056	0.071	0.065	0.116	0.103	0.215	0.184
	0.014	0.016	0.034	0.035	0.051	0.048	0.074	0.068	0.111	0.099	0.204	0.175
VI	0.012	0.015	0.035	0.035	0.050	0.049	0.076	0.070	0.114	0.101	0.213	0.185
	0.018	0.021	0.037	0.039	0.055	0.051	0.069	0.063	0.109	0.096	0.205	0.176
Std. dev.	0.0038	0.0042	0.0024	0.0025	0.0039	0.0032	0.0038	0.0042	0.0031	0.0026	0.0044	0.0053
Regression coefficient[c]	0.01959[d]			0.01623[e]								
S_b	0.000131			0.000135								
Deviation from regression	0.00366			0.00379								
Variance												
Within samples	0.00000628			0.00001506								
Between samples	0.000015			0.0000284								
F[f]	2.39			1.886								

[a] Samples refer to set of standards heated, cooled, and read as one group.
[b] A = absorbance.
[c] Computed using all observations individually.
[d] All statistics below refer to data at 544 mμ.
[e] All statistics below refer to data at 560 mμ.
[f] Not significant at 5% level.

Table IV. Absorptivity and Slopes of Various Carbohydrate–N-Ethylcarbazole Compounds

Compound	a_{544}[a]	a_{560}	Slope_{544}	Slope_{560}	$\frac{\text{Slope Compound}}{\text{Slope Arabinose}}$ 544	$\frac{\text{Slope Compound}}{\text{Slope Arabinose}}$ 560
Arabinose	2600	2080	0.0187	0.0155		
Xylose	4980		0.0334	0.0288	1.79	1.86
Ribose	2690	2080	0.0178	0.0143	0.95	0.92
Glucose	2440	2840	0.0115	0.0137	0.61	0.88
Arabinose	3000	2520	0.0181	0.0148		
Fructose	4530	5320	0.0264	0.0309	1.46	2.09
Galactose	2100	2460	0.0125	0.0146	0.69	0.99
Mannose	1790	2150	0.0096	0.0116	0.53	0.78
Maltose	5330	6150	0.0169	0.0206	0.93	1.39
Arabinose	2440	2070	0.0170	0.0141		
Sorbose	4680	5450	0.0280	0.0321	1.65	2.28
Arabinose	2600	2050	0.0149	0.0122		
Lactose	3870	4500	0.0098	0.0118	0.66	0.97
Arabinose	2630	2140	0.0180	0.0146		
Rhamnose	1980	1910	0.0136	0.0119	0.76	0.82
Arabinose	2970	2610	0.0188	0.0159		
α-Methyl glucoside	1220	1500	0.0074	0.0086	0.39	0.54
Fucose	770	740	0.0054	0.0052	0.29	0.33
Arabinose	2980	2500	0.0198	0.0168		
Lyxose	3180	2620	0.0223	0.0189	1.13	1.12
Turanose	5340	6240	0.0150	0.0178	0.76	1.06
Sucrose	5210	6180	0.0149	0.0176	0.75	1.05
Melibiose	4120	4980	0.0113	0.0134	0.57	0.80
Arabinose	3180	2880	0.0252	0.0235		
Trehalose	4920	5760	0.0133	0.0161	0.53	0.69
Melezitose	8980	10790	0.0177	0.0211	0.70	0.90
Arabinose	2870	2370	0.0198	0.0164		
Furfural	5300	4110	0.0586	0.0456	2.96	2.78

[a] Wave lengths are given in mμ.

where a is the absorptivity, A is the absorbance, b is the path length, and c is the concentration in moles per liter. The values were averaged to give the a_{av} found in Table IV. These values are not absolute, but indicate the order of magnitude because a_{av} for arabinose varied from 2440 to 3180 while the slope varied from 0.0149 to 0.0252 at 544 mμ.

The slope per milligram of carbohydrate was calculated using the formula

$$m = \frac{Sxy - n\bar{x}\bar{y}}{Sx^2 - n(\bar{x})^2}$$

where x is the concentration, y is the absorbance, n is the number of observations, $\bar{x}$ is the mean value of x, and $\bar{y}$ is the mean value of y. A set of arabinose standards was run from each bottle of reagent and both calculations made. This served to check variations in the reagent due to differences in lots of acid or in the N-ethylcarbazole. Thus calculations for each compound listed in Table IV should be compared with the values for arabinose which are given with the group.

Table IV indicates that routine readings using the spectrophotometer should be made at 560 mμ; at this wave length the majority of the compounds tested gave a slope ratio of approximately 1, compared with arab-

ose. Sorbose, xylose, and fructose e notable exceptions; each yields out twice as much color per milligram the standard. The methyl sugars ose and rhamnose as well as α-ethyl glucoside yield substantially ss color than might be expected on a illigram basis. Glucosamine hydro-loride, ascorbic acid, and malic id showed no perceptible color at a oncentration of 10 mg. per liter. The eactivity of the carbohydrates is ependent to a large extent upon heir structure, which probably explains uch of the variation in the data of able IV.

A comparison of the color produced y arabinose with that yielded by its rimary degradation product, furfural 9), would indicate about a 55% con-ersion of arabinose to furfural by this nethod. Because arabinose has been ound to produce 76% of its theoretical ield of furfural (*6*) apparently only a wo-thirds conversion is accomplished nder the conditions of this method.

DISCUSSION

The method described has been used or several thousand determinations, oth routine and experimental, and was found to be simple in operation nd relatively rapid. The lack of salt effect makes it readily usable for sea water as well as for biological fluids. Lewis and Rakestraw (*8*) have used both the Erdman *N*-ethylcarbazole and anthrone methods for determining total carbohydrates in sea water and concluded that the two methods were approximately equal in sensitivity to most sugars, but that anthrone was much less sensitive to arabinose and xylose. The sensitivity of the *N*-ethylcarbazole reagent has been increased at least three times by the modification described here; 3 γ of total carbohydrate per sample (1 mg. per liter) may be determined accurately. This compares favorably with other general methods of carbohydrate determination such as indole and sulfuric acid, 1-naphthol and sulfuric acid, or tryptophan and sulfuric acid, all of which require samples containing 10 γ of carbohydrate per ml. (*4*). Only the cysteine, carbazole, and sulfuric acid method of Dische and Borenfreund (*5*) is as sensitive, and in that method the color maximum is not developed for 18 hours.

Although most of the routine work was done with the Fisher Electrophotometer with the special interference filter, the method is equally adaptable to the use of the Beckman spectrophotometer without any decrease in speed of analysis. In the latter case it is recommended that readings be made at 560 mμ in accordance with Table IV, unless the sugars being determined are known to be pentoses. Furthermore, a 5-cm. cell should be used for concentrations below 4 mg. of carbohydrate per liter, to increase the accuracy of the readings.

With the precautions mentioned, this method is easily adaptable to routine use. Under ideal conditions, 96 samples can be run during the working day. Slight modifications in the time of heating may be made if the standards are run in the same manner. Variations in sample volume are also possible; the method is adaptable to biochemical or clinical work using 1 ml. of sample, if the ratio of 9 parts of reagent to 1 part of sample is maintained, and if about one fifth of the total volume of reagent is added before the standing period.

LITERATURE CITED

(1) Collier, A., *Am. Wildlife Conf., Trans.* **18**, 463 (1953).
(2) Collier, A., Ray, S. M., Magnitzky, W., *Science* **111**, 151 (1950).
(3) Collier, A., *et al., U. S. Fish Wildlife Serv. Fishery Bull.* **54**, 167 (1953).
(4) Dische, Z., *Methods of Biochem. Anal.* **2**, 313 (1955).
(5) Dische, Z., Borenfreund, E., *J. Biol. Chem.* **192**, 583 (1951).
(6) Dunlop, A. P., Peters, F. N., "The Furans." ACS Monograph Series, No. 119, p. 292, Reinhold, New York, 1953.
(7) Erdman, J. G., Little, A. B., "Analysis of Marine Coastal and Estuarial Waters," p. 50, 1950. Multiple Fellowship of Gulf Research and Development Co. at Mellon Institute, Pittsburgh (unpublished).
(8) Lewis, G. J., Jr., Rakestraw, N. W., *J. Marine Research* (*Sears Foundation*) **14**, 253 (1955).
(9) Rice, F. A. H., Fishbein, L., *J. Am. Chem. Soc.* **78**, 1005 (1956).

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